EXTRA-SOLAR PLANETARY SYSTEMS

Alfred Vidal-Madjar
Institut d'Astrophysique de Paris, CNRS (UMR 7095), Université Pierre et Marie Curie, 98 bis boulevard Arago, 75014 Paris, France

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Contents

Summary

This chapter presents a new field on extra-solar planets studies. First the question of the definition of an extra-solar planet is raised followed by the presentation of the main instrumental techniques used to discover them. The way an observational discovery is made is emphasized here in order to show the possible difficulties one has to face when trying to investigate in an unknown region of our knowledge. In 1995 the first extra-solar planet orbiting a normal main sequence star was discovered around the star 51 Pegasi. The first planet to transit in front of its star every orbit is HD209458b, a so called "hot Jupiter", the Rosette Stone of all presently discovered planets. That new observational situation, a transiting planet, triggered several attempts to study even the

planet's atmosphere which lead to the unexpected discovery of a very extended atmosphere finally shown to be flowing away from the planet, now nick named for that reason “Osiris” (the Egyptian god who lost part of his body). Different approaches are outlined that are used in the search for extra-solar planets. Perspectives strongly dependant upon the future instrumentations are finally presented in order to give a more precise time frame for the discoveries to come and a plausible time when finally another Earth able to support life will be eventually found.

1. Introduction

Greeks very early noted these “wandering stars” called “asters planetai” because they have apparent motions unlike the “fixed stars”. Our brightest planets, Mercury, Venus, Mars, Jupiter and Saturn were then already identified but the planet family at that time included also the Moon and the Sun which presented also obvious apparent motions. Historical events, called “transits”, which are rare short periods of time when a planet passes in front of the solar disk could be traced back to Ptolemy who very early mentioned in his “Amalgest” that no detection of transits was not in contradiction with Mercury and Venus being closer to the Earth than the Sun (in the geocentric system only considered at that time) simply because they could be either too small to be detected or that their orbital plane could be slightly tilted to the solar one.

In 1607 Johannes Kepler thought he directly observed a predicted Mercury transit but in fact only followed sun spots. He however predicted the next transits of Venus and Mercury to take place in 1631 following the extremely accurate Tycho Brahe’s observations of the planets. The first transit to be observed was the Mercury transit in 1631 with the best observations leading Pierre Gassendi to evaluate its diameter to be less than 20 arcsec, much smaller than ever thought before. The modern scientific sense of planets as “worlds that orbits a star” is from 1640, after the Nicolaus Copernicus heliocentric description was well established.

First ideas about the planetary system formation came from Immanuel Kant and Pierre-Simon Laplace. Laplace writes in “Exposition du système du monde” (1795): “*The elements of the planetary system can shed light on its origin. When considered attentively, we are surprised to see that all the planets move around the Sun, from west to east, and almost in the same plane; the satellites move around their planets in the same direction and almost in the same plane as the planets; and last, the Sun, the planets and the satellites rotate in the same direction and almost in the same plane. One can speculate that the planets were formed at the successive limits [of the Sun atmosphere] through the condensation of the gas it had left in the plane of its equator*.” It is quite amazing to read again Laplace’s original ideas about the Solar System formation. He proposed that the Solar System may have formed from a primordial disk shaped nebula. It took a long time to find observational confirmation of these ideas. But now, the various steps of planetary systems formation are observed clearly confirming his views. Finally, the first extra-solar planet, 51 Peg b, orbiting the solar like star 51 Pegasi, was detected in 1995 by Michel Mayor and Didier Queloz, two Swiss astronomers, who discovered it from the 193 cm Telescope located at the Observatoire de Haute Provence in France.

Definition of an extra-solar planet as well as the successive steps of planetary systems formation will be briefly given in the following sections. Then the different detection techniques will be presented in order to show how difficult the discovery of an extra-solar planet is. Then from the statistical behavior of the observed extra-solar planets the general characteristics of extra-solar planetary systems will be discussed, including of course the unexpected surprises. The detailed analysis of some of the extra-solar planet's atmospheres will then be presented in order to show how fast this difficult observational domain evolves. In conclusion some perspectives related to the future of that new and exciting domain of astrophysics will be given having in mind the aim of detecting life on some other "Earth".

2. What is an Extra-solar Planet?

Among the duties of the Working Group on Extra-solar Planets (WGESP) that the International Astronomical Union organized in 2003 was the need for a clear definition. It was promptly recognized that this could only be a working definition subject to changes depending upon what we would learn later about the population of the discovered extra-solar planets.

The current definition of what is considered to be an extra-solar planet is:

1. *Objects with true masses below the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses for objects of solar metallicity) that orbit stars or stellar remnants are "planets" (no matter how they formed). The minimum mass/size required for an extra-solar object to be considered a planet should be the same as that used in our Solar System.*
2. *Substellar objects with true masses above the limiting mass for thermonuclear fusion of deuterium are "brown dwarfs", no matter how they formed or where they are located.*
3. *Free-floating objects in young star clusters with masses below the limiting mass for thermonuclear fusion of deuterium are not "planets", but are "sub-brown dwarfs" (or whatever name is most appropriate).*

These statements represent a compromise between definitions based purely on the deuterium-burning mass and on the formation mechanism, and, as such do not fully satisfy anyone on the WGESP. However, the WGESP agrees that these statements constitute the basis for a reasonable working definition of a "planet" at this time. We can expect this definition to evolve as our knowledge improves.

From this definition "pulsar planets" are considered as extra-solar planets. However, since only four of them were discovered, starting in 1992, around fast rotating pulsars and presenting extremely low masses even smaller than the Earth mass, their formation history being certainly very far from what we consider planets as in our own Solar System, these bodies will be only briefly mentioned in the following presentation since they could be considered as different astrophysical objects. Also the "free floating" objects, away from any "parent" star are not considered here due to their probable different history. Three candidates for such objects were discovered so far although some of them may be actually circulating a brown dwarf type star at a wide orbit.

3. Planetary System Formation

Following Kant-Laplace description the formation of a planetary system goes through several essential steps which are today recognized as (see Figurer 1 illustrating these steps along with the corresponding observational proofs we have):

- Collapse of a large interstellar molecular cloud; it break ups into small parts which will produce tens to hundreds of stars with planetary systems; during that collapse the gas and dust accelerate their rotation (angular momentum is conserved) and the lump of the original molecular cloud condensates into a central star and a surrounding disk-shaped cloud called “protoplanetary disk” which may contain as much mass as the newly born but still hidden central star; the size of that protoplanetary disk is often thousand times the size of our own Solar System; during the first hundred thousand years, the protoplanetary disk is still embedded within the main interstellar molecular cloud; dust condenses in its equatorial plane to produce particles which rapidly grow in size reaching even very large dimensions up to several tens to hundreds of kilometers; strong polar jets start to show up throwing away some of the angular momentum excess; the surrounding giant molecular cloud starts to evaporate as soon as a few very massive and bright stars simultaneously are born nearby (first step shown in Figurer 1);
- During the first million years, the protoplanetary disk may show up out of the interstellar molecular cloud and may then be directly observed with the new born star that starts shining at its center; some of the disks suffer from strong evaporation processes due to the intense winds and light coming from nearby massive stars; the young stars has very strong winds ejecting additional matter and angular momentum away (second step shown in Figure 1);
- In the following 10 million years the giant planets form from the collapse of gas from the surrounding protoplanetary disk on the largest solid bodies formed from the dust, of about 15 earth masses, which are massive enough to play the role of seeds via their strong gravitational attraction; because the lifetime of the protoplanetary disks is known to be of only several million years, and a lot of material is required for massive planet formation, the formation of giant planets like Jupiter has to take place during these first 10 million years; once formed, these giant planets still grow up at the expense of the remaining disks of dust and/or if more than one giant planet is present, the remaining dust could be confined within rings (third step shown in Figurer 1);
- During the following few hundreds of million years, the vanishing protoplanetary disks are replaced by “debris disks” which were discovered around few nearby stars as dusty disks of mass less than $1/100000^{th}$ of the original protoplanetary disk mass; this small amount of dust and gas is produced from the collisions and evaporations of huge number of orbiting bodies still present in the original disk equatorial plane; these numerous collisions (during the period of intense bombardment known to have lasted about 700 million years in our own Solar System) break apart most of the remaining bodies while few of them, the larger ones, keep growing to finally form telluric or “Earth like” planets (fourth step shown in Figurer 1);

- And finally during the following few billion years, the star shines more steadily as long as its hydrogen fuel is available for nuclear fusion, and the formed planetary system then looks like ours, with several planets orbiting around a central star (fifth step showing our “well known” Solar System in Figurer 1).

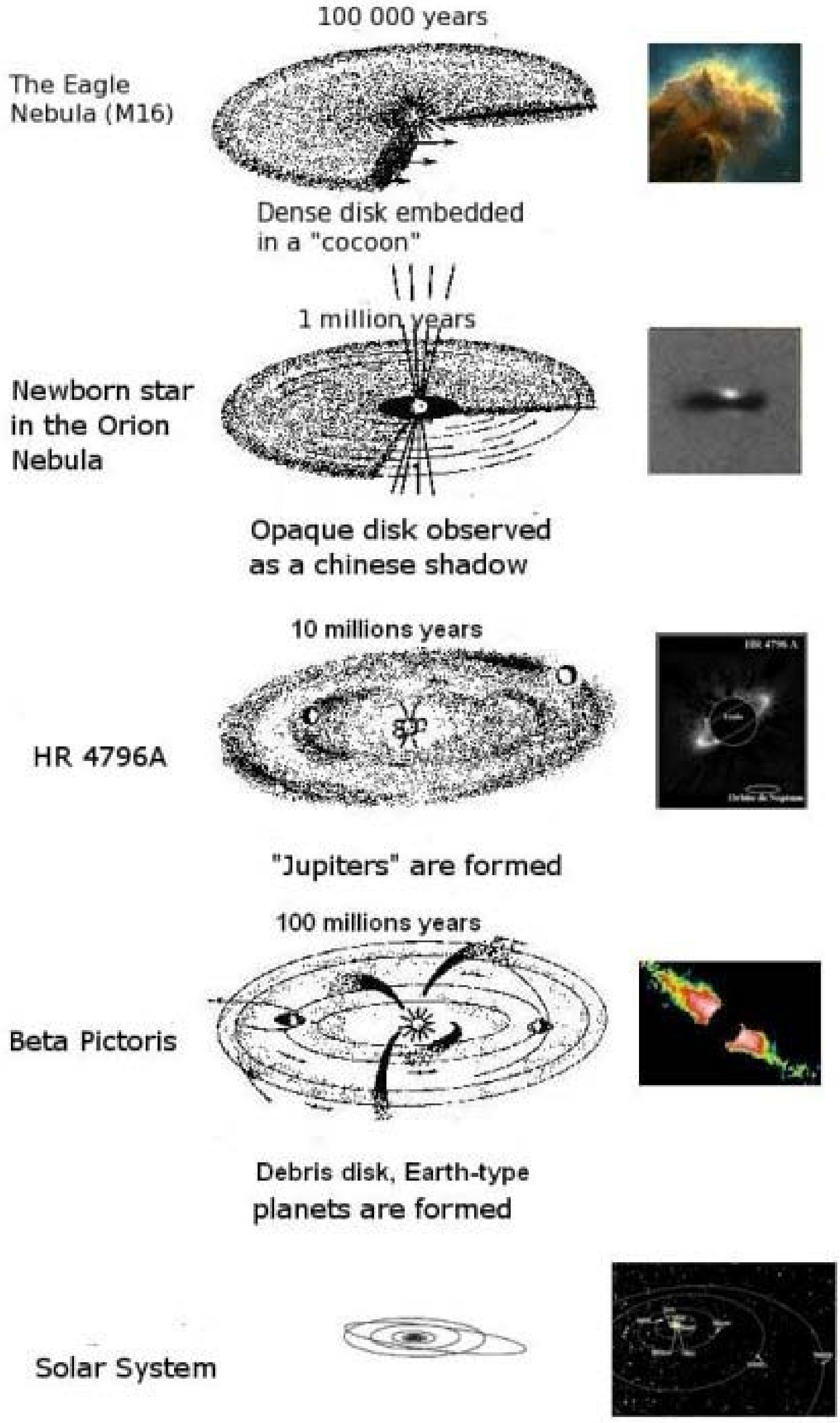

Figure 1: This sketch represents the successive steps of a planetary system formation. From top to bottom the successive epochs of these steps are noted along with indications of their main characteristics (see text for more details), the last step corresponding to billions of years, *i.e.* our Solar System. Pictures are shown on the right hand side of this figure (with the corresponding object name given on the left hand side) in order to show that all these steps are now directly identified via observations. The three earlier steps were imaged with Hubble Space Telescope (NASA & ESA) instruments, the debris disk of β Pictoris was observed at the ESO 2.2m ground based telescope and the last image represents a reconstructed view of the Solar System as seen from the NASA Voyager spacecraft when moving away from it.

All the previously described steps were observed in detail as shown in the small images added in Figure 1: the three first ones showing evaporating cloud, protoplanetary disk seen edge on with the star shining at its center and ring of dust probably produced by two unseen orbiting giant planets (© Hubble Space Telescope, NASA), the one showing the debris disk around the star β Pictoris seen edge on as a dust band crossing through the hidden central star (© Institut d'Astrophysique de Paris, CNRS, UPMC) and finally a back view of our own Solar System as seen by Voyager (© Voyager, NASA), when moving away from it. This gives strength to the protosolar nebula scenario supposing a planetary system formation which starts from the collapse of a lump of gas originally embedded inside a giant interstellar molecular cloud, as first Kant and Laplace have speculated.

Many other types of scenario were proposed to explain the formation of a planetary system. Almost all of them failed for some observational constraint. For example, the very presence of deuterium (heavy hydrogen) on the Earth and on the giant planets of the Solar System demonstrates that all these bodies must have formed from material not extracted from the star itself since it is known and observed that deuterium is absent in solar material because it is easily and thus immediately burned in the thermonuclear reactions that makes the star shine. All types of stellar collision scenario able to extract some matter from the star itself were thus abandoned, at least as the main type of formation scenario.

One possible alternative scenario is however left open. It speculates that during the giant interstellar cloud collapse, when fractionation takes place to provide hundreds of lumps leading to hundreds of new stars, this very process could not only produce gravitationally multiple lumps leading to multiple star systems as often observed (double star systems are even more common than single stars, and our closest neighbor star in the Galaxy, Proxima Centauri, is within a triple star system), but also to lumps extremely unbalanced in mass, some of them of the size of giant planets of about $1/1000^{th}$ of the star mass. This is called the gravitational collapse scenario which could at least explain part of the discovered planetary systems characteristics as it will be discussed later.

In Figure 1 several steps of the planetary system formation are shown including their approximate duration. To better perceive the large differences in time between these steps, let us assume that a billion years lasts only one month, a duration we are much more familiar with. Our Solar System lasts from about four month and a half while the time to complete a planet like the Earth should be of the order of few days, to finalize the giant planets and in particular Jupiter, only 7 hours were needed while our protoplanetary disk was merging out of its interstellar cloud after less than 40 minutes, our Sun being born less than 4 minutes after the interstellar cloud collapse.

To better show how a formed planetary system could look like, let us present our Solar System in a little more detail. It has eight planets orbiting the Sun, all on nearly circular orbits. Four small ones, the closest to the Sun, often called telluric planets because they are small and look like more or less the Earth. Four more distant ones, much larger, called giant planets. They are also heavier from tens to hundreds times the Earth mass. The largest planet is Jupiter. It however represents not more than 1/1000th of the solar mass. In other words, a planetary system has almost all its mass within the central star(s) while on the other hand almost all the angular momentum is within the planets (their orbital motion). Additionally, there are also asteroids within asteroid belts, residues of the planetary formation process within the protoplanetary and the debris disk, comets coming from collisions or orbital perturbations within the asteroid belts or from a more distant and larger belt, called the Kuiper belt, made of relatively large objects including Pluto that was until recently classified as the ninth planet, and finally additional comets which seem to come from a very distant reservoir of objects called the Oort cloud surrounding the Solar System at very large distances.

To give a better view of our Solar System scale, changing our Sun into an “orange” will change all planets into small almost invisible “pin heads” or “small peas” orbiting around the “orange” at about 5m for the Earth, 25m for Jupiter and up to about 150m for Neptune, the most distant planet. Then the Kuiper belt extends beyond Neptune’s orbit up to about 1 or 2 kilometers, supposed to be formed of possibly millions of objects, to finally reach the Oort cloud at few hundred kilometers from the central star. At this scale, the closest star, Proxima Centauri, is another “orange” floating in its triple system of stars at about 1300 km from there! This simple image shows how hard it is to try to detect extra-solar planets which are in fact similar to obscure “pin heads” or “small peas” to be seen around extremely bright “oranges” at thousands of kilometers away. No surprise it took a very long time for observational astronomy to meet such a challenge.

4. The Different Detection Techniques and Search Strategies for Extra-solar Planets

It took almost the whole 20th century to solve that question since it was guessed or expected that planets should probably orbit many stars but it was impossible to say if this was a common or rare situation. Very early in the middle of the last century Peter van de Kamp tried to detect planets around nearby stars by attempting to see the induced gravitational wobble of the central star (astrometry). In the 1960s he claimed that the nearby Barnard star had a planetary companion. This is however now not confirmed by much higher precision observations. He unfortunately died in 1995, the year when the first confirmed extra-solar planet was finally discovered.

As just mentioned, astrometry was the first technique used to detect extra-solar planets. With this approach being however not yet successful, let us see now the different possible approaches used to discover extra-solar planets and how successful they are. They are grouped in two broad categories, the direct and indirect methods. The direct ones try to have access to observations related to the planet itself like detecting photons emitted or altered by the planet. Direct imaging of a planetary system is of course the final aim of such approaches but is still extremely difficult and not yet successful in terms of planetary systems relatively similar to our Solar System. In such systems the planetary emission is from billions to millions of times less than the stellar one which explains why this approach is such a challenge. The first ***direct*** detection of a planetary mass object, 2MASSWJ1207334-393254b often "simply" called 2M1207b, was however completed in 2003 by Gael Chauvin, Anne-Marie Lagrange, Ben Zuckerman and collaborators: an object of about $5M_{\text{Jupiter}}$ was directly imaged orbiting at about 46 AU from an extremely low mass star, more probably a brown dwarf with an evaluated mass of only $25M_{\text{Jupiter}}$. This definitively establishes that the direct detection of extra-solar planets is now accessible to our large ground based instruments equipped with adaptive optics. This remains true even if there is still a debate if this object of $5M_{\text{Jupiter}}$ is really a planet; indeed, the strict definition of a planet is that it must have a mass smaller than $13M_{\text{Jupiter}}$ and be in orbit around a star (of mass higher than $70M_{\text{Jupiter}}$) and not in orbit around a brown dwarf (of mass ranging between 13 and $70M_{\text{Jupiter}}$). The reason is that the formation scenario may differ from a planet formation scenario and be similar to a binary star formation: it is possible that the two objects of relatively similar masses were formed in the same way by gravitational collapse within the primordial nebula, the smaller one thus not being formed in a protoplanetary disk around the brown dwarf, i.e. not like a planet. It is however important to stress that it is also possible that planets recognized officially as such, discovered around stars, could also be formed by gravitational collapse as suggested by Allan Boss in 1997. The debate to know how each planet was formed will probably not be closed soon. The favorable situation related to this first detection was the presence of the very dim nearby brown dwarf. This approach will be developed in the future but needs still a lot of instrumental improvements either in ground based or in space observatories.

The methods successful now belong to the indirect method category although in few cases some photons were detected as coming from the planet. This happens when the transit method is used which searches for small stellar eclipses due to a planet passing in front of the stellar disk. All other approaches are indirect, i.e. they try to detect the perturbation imposed to the star by the planetary gravitational pull. This leads to the first approach already mentioned, astrometry, which tries to detect the star wobble over the background sky, the radial velocity technique which measures the perturbations of the stellar motion in terms of velocity changes relative to the observer, the timing methods able to detect again the central object motion via detectable changes of a precise clock related to that object, and finally the gravitational microlensing approach that detects anomalous enhancements of remote stellar light flux by a planetary system passing in front of it.

4.1. Search by the Timing Method

The method of search for extra-solar planets by timing consists of using a very precise clock in the studied system in order to see whether abnormal shifts appear in the course of time. Thus not only planets would be detectable, but even planetary satellites. The very regular clocks available are of course the pulsars, the eclipsing binaries, the pulsating stars or even the systems with a known planet detected by its transits.

4.1.1. Pulsars

The first planets detection (a system of two, then three planets) was made around the millisecond pulsar PSR B1257+12 by Alexander Wolszczan and Dale Frail in 1992. Although according to the strict definition these objects could be considered as extra-solar planets, their very different origin and conditions there invites us to call them "pulsar planets", to distinguish them from any other planet found orbiting "normal" sunlit star. They represent however the first extra-solar planets discovered to date on regular orbits and the least massive known. The three identified planets indeed have masses of 0.019, 4.250 and 3.873 terrestrial masses, respectively. With time, the continuation of the precise observation of the pulses arrival times allowed both the discovery of a third planet in the system and to show that the evolution of the pulses arrival times is not only compatible with the presence of the planets previously detected but is even compatible with the occurrence of the gravitational interaction between the planets perturbing their orbits. These results, though in a context slightly different from that of the search for extra-solar planets in a strict sense, show at least the remarkable capacities of the timing method which allowed the detection of a body of the mass of the Moon as well as the tiny effect of mutual gravitational planetary interactions within the same system. In addition, via the study of the system stability, even the possibility of the presence of asteroids belts is now discussed. Only one more "pulsar planet" was detected, around PSR B1620-26, which shows that these "exotic" objects are probably quite rare.

4.1.2. Eclipsing Binaries

Like pulsars, binary stars with eclipses give us access to another extremely precise clock. Again, following the precise evolution of the eclipse times could reveal the presence of additional objects not yet identified but present in the system via their gravitational interaction. The moment of the eclipses time shift is $\Delta T = M_{\mathrm{P}}(a.\sin i)/M_{\mathrm{B}}c$, where M_{P} represents the mass of the third body (planet), M_{B} the mass of the binary system, **a** the size of the planetary orbit around the binary system, i the inclination to the line of sight and c the speed of the light. This relation shows that with a precision of a few seconds over the moments of the eclipses, a planet of the mass of Jupiter may be detected. The advantages of this approach are that the level of photometry needed to follow such binaries requires only relatively small telescopes and that the number of binaries which can be thus followed is relatively large (~ 4000 currently known in our Galaxy), and in a number of cases (~ 250) the moment of the eclipse can be known with few seconds accuracy. Furthermore, the mass of the binary star being measured relatively precisely by traditional methods, the mass of the additional body in the system can thus be evaluated precisely. The disadvantage of this approach is on the other hand that it gives access only to an upper limit to the mass and size of the orbit of the third body present in the system (only $M_{\mathrm{P}} = f(\sin i)$ and $a.\sin i$ are accessible). However, the combination of this type of measurements with precise astrometric observations can solve the system uncertainties. The thorough study of a binary system with eclipses was carried out to date on CM Draconis, in which shifts by 5.74 s of the moment of the eclipses between 1994 and 1999 were observed. These variations could be compatible with a planet from 1.5 to 3 times the Jupiter mass orbiting between 1.1 and 1.45 AU (one Astronomical Unit is equal to the Sun-Earth average distance) from the barycenter of the system. However, a longer monitoring of the system is essential to confirm this result.

4.1.3. Systems with a Planet in Transit

In the same manner, the survey of timing measurements of planetary transits (a star-planet clock is equivalent to a binary star clock) can allow the detection of additional planets in the system, even if the planet masses are close to that of the Earth as predicted by Eric Agol and his collaborators (2005). In effect the precise timing of the planetary transits can allow the detection of another planet in the system with about the same degree of accuracy. There is however a new opportunity in this approach which would make it possible to also detect the presence of satellites in orbit around a transit planet. This was applied to the case of HD209458b for which it was shown that this planet could not have satellites of mass larger than about $3M_{\text{Earth}}$ without being revealed by a shift of the transits time which would have been then higher than the 80 seconds of precision reached. The greatest sensitivity of this method in the case of satellites comes from the fact that their gravitational interaction with the planet they are orbiting is much more important, their position on their orbit around planet allowing much more effective shifts of the transit times for relatively small mass objects. To give a more quantified idea, with an accuracy of 5 seconds on the transit times, the detection of a disturbing planet of about $1M_{\text{Jupiter}}$ at 10 UA in the system would become possible.

4.1.4. Pulsating Stars

Another possible clock could be found in the case of a pulsating star. In 2007 a first planet of about 3.2 times the Jupiter mass was discovered by Roberto Silvotti and collaborators (2007), orbiting the star V 391 Pegasi at a distance of about 1.7 AU, with a period of 3.2 years. This pulsating star, by the periodic changes of the pulse arrival time over several years revealed the presence of the orbiting planet. Again, this new discovery shows that planets at less than about 2 AU could survive the red-giant phase of the star. V 391 Pegasi already went through that phase and its maximum radius may have reached 0.7 AU, while the orbital distance of the planet before that phase is estimated to be about 1 AU. This detection of a planet orbiting a post-red-giant star demonstrates that planets like some of the Solar System ones may survive the huge change in size of their star, which is expected to happen to our Sun in about 5 billion years.

The timing approach presents the following characteristics of detection:

- No need for photons coming from the planet itself;
- Good sensitivity to very distant star/planets systems at ~10 kpc or more;

- Absolute need of a precise enough “clock” within the studied system;
- Good sensitivity to small planets possibly down to earth and even moon size planets;
- About 5 extra-solar planets were discovered before the end of 2007 by timing methods.

4.2. Search by the Radial Velocity Method

Stars contain millions of extremely precise clocks: the vibrating atoms, ions and molecules present in their upper atmosphere. Each species has its own modes of vibration producing millions of lines in the stellar spectra since each species absorbs and radiates the stellar light at the wavelengths which precisely correspond to these modes. Exactly as in the case of the timing method, *all* these clocks are perturbed by the stellar motion induced by the gravitational pull of the putative orbiting planet. The accuracy required to detect a planet is however extremely high and observing few of these “atomic”, “ionic” or “molecular” clocks is not enough to reach it. Observing on the contrary *all* clocks simultaneously gives access to the needed accuracy. Today, following the first success in 1995 by the Swiss team of Michel Mayor and Didier Queloz - the detection of a planet orbiting 51 Pegasi – rapidly followed by the US team led by Paul Butler and Geoffrey Marcy (see their “Catalog of Nearby Exoplanets” published in 2006) this approach is certainly the most efficient having now permitted the detection of about 250 extra-solar planets (as for autumn 2007), which means more than 95% of all discovered extra-solar planets.

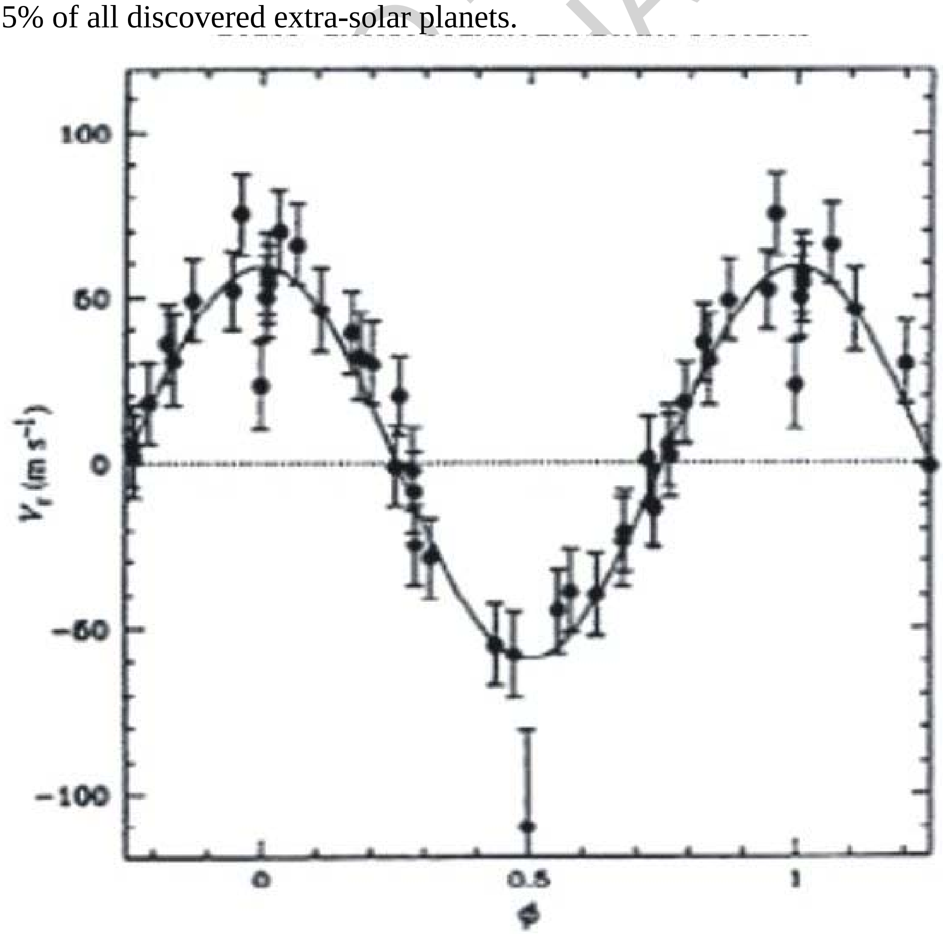

Figure. 2. The periodic changes in the velocity of the star 51 Peg due to the planet, from the discovery paper bringing the first extra-solar planet around a Sun-like star published by M. Mayor and D. Queloz in 1995.

This large number starts to give access to the statistical behavior of the discovered planets which reveals several important surprises. Among them, are the confirmation of the presence of giant planets orbiting very close to their parent star and for that called “hot Jupiters”, the fact that many planets are on very eccentric orbits unlike the ones in the Solar System where all planetary orbits are almost circular, and that most of the planets are found around stars containing more heavy elements than the Sun. In addition, models of planet formation predict that the rocky planets of masses lower than a few terrestrial masses can be formed between 0.1 and 3 AU, that icy planets of all possible masses (from Earths to Jupiters) can be formed beyond 3 AU and that finally the gas giants of Jupiter masses can be found anywhere between 0.1 and 10 AU. According to those models, planets with masses between 10 and 100 times the mass of the Earth should not reside in a zone between 0.1 and 3 AU. However, the most recent discoveries of low mass planets by the radial velocity method, on the contrary, show that most of these new extra-solar planets are found precisely in the forbidden zone. We can see that we are not at the end of our surprises.

This radial velocity approach presents the following characteristics of detection:

- No need for photons coming from the planet itself;
- Sensitivity to relatively nearby star/planets systems, up to ~1 kpc (except very few cases);
- More difficult to detect planet around giant, fast rotating and active stars;
- Good sensitivity to small planets soon down to few earth mass planets;
- Easier to detect planets at small star/planet distances, needs time (few orbits) to detect distant planets;
- Not sensitive to face on planetary orbits;
- 251 extra-solar planets were discovered before the end of 2007 by this method.

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Biographical Sketch

Alfred Vidal-Madjar is astrophysicist and Directeur de Recherche at the Institut d'Astrophysique de Paris, a laboratory of the Centre National de la Recherche Scientifique (CNRS) and of the Université Pierre et Marie Curie (Paris 6) of France.

Born in Cairo (Egypt) on September 13th, 1942 Scientific studies at Ecole Polytechnique, Paris, France, 1961 – 1963 Licence in Mathematics, University of Paris 6, France, 1965 Fellowship at Centre National d'Etudes Spatiales (CNES), France, 1967 – 1971 Ph. D. in Astrophysics, University of Paris 6, 1973 Research at Centre National de la Recherche Scientifique (CNRS), since 1972 Teacher in physics at Ecole Polytechnique, 1978 – 1992 Teacher in astrophysics at Ecole Polytechnique, 1999 - 2000

His research contributions in astrophysics, at the end of year 2007, represent 380 different titles including 243 refereed articles, 84 contributions in Meeting Proceedings, 44 invited lectures and 9 books. They concern a great variety of topics concerning very different research fields which could be summarized as follows:

1) His contribution in using several UV space missions, from Copernicus to FUSE. He was the French PI of the FUSE program, the Far Ultraviolet Spectroscopic Explorer, an US, NASA, Canadian, CSA and French, CNES collaboration, the satellite having perfectly operated in orbit from 1999 to 2007. Among many studies he contributed to the determination of the interstellar deuterium abundance, an evaluation related to cosmology via the amount of baryonic matter in the Universe;
2) He initiated the first detailed analysis of the local interstellar medium pointing out the existence of a very nearby interstellar cloud;
3) He discovered the intense cometary bombardment on the star β Pictoris. This most important finding was made in 1988, i.e. 7 years before the announcement of the first exoplanet in 1995. In the β Pictoris he may have contributed to the discovery of the first extra-solar planet however unconfirmed for the moment;
4) He participated to the first observation of a gravitational microlensing phenomenon with the EROS French collaboration. The Nature 1993 paper relative to this discovery was number 4 at the world level for its quotation index, irrespective of the research field. One important consequence of this research was that unseen baryonic matter in the Galaxy cannot be hidden under the form of massive Compact Halo Objects (MACHO), the missing mass question being still an open one;
5) More recently, he and his group were the first to detect the presence of escaping hydrogen, oxygen and carbon in the exosphere of an exoplanet which leads to the definition of a new class of such objects: hot and evaporating away planets.

He is presently working at the Institut d'Astrophysique de Paris.

Books by Dr. Vidal-Madjar:

« Il pleut des planètes », Hachette Littératures, 1999.

« Sommes-nous seuls dans l'Univers ? », Fayard, 2000.

« Il pleut des planètes », Hachette Littératures, Pluriels, revised and re-edited in 2005.
Memberships in professional societies:

Member of the International Astronomical Union since 1973

Member of the Société Française d'Astronomie et d'Astrophysique since 1978

Awards:

Silver Medal of CNRS, 1988

Chevalier de l'Ordre National du Mérite, 1989

Centre National d'Etudes Spatiales Medal, 2002

Prix Ampère de l'Académie des Sciences, 2007