SMALL BODIES AROUND OTHER STARS

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Abstract. We briefly review recent advances in the observation and study of planetary bodies in extra-solar systems. We summarize in particular the main physical properties of the β-Pictoris dust disk, and the status of new disk observations. Theoretical implications of infalling discrete bodies are considered, in particular, the existence of possible perturbing planet(s) causing this influx. Such planets could spectacularly disturb circumstellar dust disks, thus revealing themselves in spite of their intrinsic faintness as mere point sources. Finally, we describe the recent possible discovery of at least two planets around a pulsar. This underlines the potential existence of planets in rather exotic circumstances.

1. Introduction

It may seem rather paradoxical to study small bodies around remote objects, when it is usually so difficult to observe them around our own Sun! However, we will see in this brief review that in some specific areas we can detect planets, dust, or even comets near other stars. It is not our aim to review the theoretical work on planetary formation, nor to give an exhaustive list of observational techniques to detect circumstellar material. These tasks would in effect take much more that the few pages allowed here (see Levy and Lunine, 1993). Rather, we present recent progress in this area, and give relevant references.

The regions surrounding young stellar objects are natural sites for searching for circumstellar material in general, and extra-solar planets in particular; they are important, since they represent cocoons in which planets like those in our solar system may form. The frequency of protoplanetary systems provides a fundamental clue to better understand the origin of our own solar system. We now live a quite special epoch, because of the increasing quality of observation techniques, and in particular because the infrared (IR) is revealing colder and colder material around stars.

A good example of "cold" material detection is given by the IR excess observed around the white dwarf G29-38 (Zuckerman and Becklin, 1987, Greenstein, 1988). Modelling the spectrum of the white dwarf, these authors show that the IR flux between 2 and 5 μm is actually a signature of non-stellar material (brown dwarf or dust) around the primary. IR images of the white dwarf GD 165 subsequently showed the presence of a low-temperature companion, also interpreted as a brown dwarf with mass between 0.06 and 0.08 solar masses (Becklin and Zuckerman, 1988). Data from the Infrared Astronomical Satellite (IRAS) have now shown that most of the nearby A, F, G stars exhibit an infrared excess suggesting the presence of circumstellar dust (Backman and Gillett, 1987, Auman, 1988). Direct imaging or spectroscopic observations from the ground show that between 25 and 50% of pre-main-sequence stars and T-Tauri stars have detectable circumstellar disks (see

A. Milani et al. (eds.), Asteroids, Comets, Meteors 1993, 429–442.

reviews by Beckwith *et al.*, 1990, Beckwith and Sargent, 1993, Basri and Bertout, 1993).

As an another example we cite the ground-based detection of an IR excess around the IRAS source HD 98800 (Zuckerman and Becklin, 1993*a*). This shows that HD 98800 is surrounded, within a few AU, by an amount of dust which is about six orders of magnitude larger than the zodiacal dust in the inner solar system. In another recent observation, the Hubble Space Telescope has revealed that nearly half of the stars in the Orion nebula have circumstellar disks (O'Dell *et al.*, 1993). Among these kinds of object, the β-Pictoris disk has been extensively observed, because of its larger intrinsic brightness (Smith and Terrile, 1984, 1987, Paresce and Burrows, 1987, Telesco *et al.*, 1988, Lecavelier des Etangs *et al.*, 1993, and see the review by Norman et Paresce, 1989, and Paresce, 1992).

As we now see, complementary observations can uncover several kinds of planetary material around these stars. First, the dust can be revealed either by direct imagery or through infrared excess measurements (Section 2 and 3). Second, more "exotic" detections are provided by spectroscopic evidence for infalling bodies, a process reviewed in more detail in Section 4. Also, we will see in Section 5 that planetary perturbations on a dust disk could betray the existence of planets around some of these stars. Finally, we describe in Section 6 what could be the first discovery of extra-solar planets around pulsars.

2. The β-Pictoris dust disk : physical properties and implications

The β-Pictoris star is believed to be a young A5 dwarf with an age less than $\sim 2 \times 10^8$ years, located at 17 parsecs from the Earth, with a mass of 1.5 $M_\odot$, and a luminosity of 6 $L_\odot$ (Norman and Paresce, 1989, Paresce, 1991). Coronographic images show a nearly edge-on disk with an extension of more than 1000 AU (Smith and Terrile, 1987), and an opening angle of 8° (Artymowicz *et al.*, 1989, and see figure 1). It is probable that this disk represents a unique example of an early planetary system. In a protoplanetary disk, the dust is either primordial (nebula condensates), or produced by collisions between larger planetesimals. The age of β-Pictoris, and the tenuous density of the gas, argue in favour of the second mechanism. According to Zuckerman and Becklin (1993*b*), this should be also the case for Vega and Fomalhaut. Then, the disk corresponds to the short phase of proto-planetary evolution, after the gas shell has been ejected and when the planetesimals are still accreting into a few larger bodies. The opening angle of the dust distribution also argues in favour of larger bodies stirring the disk and providing dust through collisions.

The images furthermore reveal an asymmetry in the structure of the two ansae of the disk at large distances, the northeast projection extending to more than 1100 AU, and the southwest projection extending to only $\sim$ 900 AU (Smith and Terrile, 1987). The inner part of the disk also exhibits an asymmetry in brightness, but reversed with respect to the outer regions (Vidal-Madjar *et al.*, 1992, Lecavelier des Etangs *et al.*, 1993). These latter observations show that the disk colour drops in the blue by a factor 4 from 75 AU to 30 AU, while the disk colour is neutral in V, R and Ic. This reddening could be explained by more and more dusty ice particles when going inward.

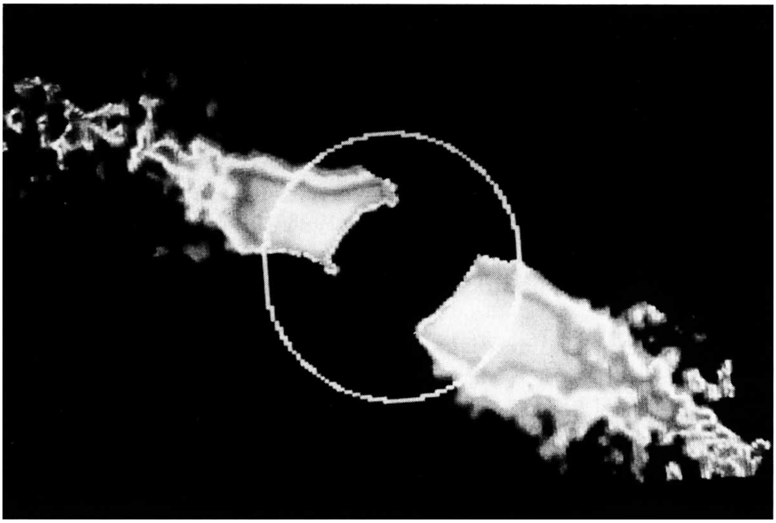

Fig. 1. The central part of the β-Pictoris disk, imaged in the V filter by an anti-blooming CCD camera (see Vidal-Madjar *et al.*, 1992 and Lecavelier des Etangs *et al.*, 1993, for detail). North is up and a 6-arcsec circle is drawn. The disk image has been radially flattened to strengthen the weakest parts. The disk is clearly detected down to 2.5 arcsec ($\sim$ 40 AU) from the star.

The combination of these data can be used to constrain the radial distribution of the dust around the star, together with the size distribution of the grains. Although there is no unique solution, some general structural features of the disk have been recognized. In one model (Artymowicz *et al.*, 1989), the grain radii are in the range 1-20 μm, with a high albedo > 0.5. The minimum grain radius is confirmed by independent observations (Norman and Paresce, 1989). The combination of IRAS and coronographic data requires that the inner part of the disk is largely cleared. However, while the existence of this clearing zone seems to be well established, its size is very model dependent, with a radius varying between 5 and 15 AU for μm-sized particles (Artymowicz *et al.*, 1989). According to these authors, the optical depth could be as large as 7×10^{-3} at the densest part of the disk and the estimated total mass of the dust disk is then one lunar mass, according to their model.

More refined models have been proposed by Backman *et al.* (1992), using visible data and IRAS fluxes, plus IR ground-based observations (10 and 20 μm). These models require a two-component disk. An outer ($r > 80$ AU) disk of icy particles, and an inner ($r < 80$ AU) disk would be made of refractory material, with a significant deficit of material with respect to an inward extrapolation of the outer component. The minimum grain size in the inner disk would be in the range $\sim 0.4 \div 3\mu$m, assuming a power law with an index -3.5 for the size distribution of the grains (i.e. the number of particles with radii between s and $s+ds$ is $dn \propto s^{-3.5}ds$).

The normal optical depth of their preferred model is $\sim 5 \times 10^{-4}$ around 20 AU. Finally, the inner disk should also have an inner limit between 1 and 30 AU, defining an innermost void.

Complementary observations include millimetre data as well as optical and IR data. The models derived from these observations indicate that large particles (at least 5 mm and possibly more) should be present around β-Pictoris (Chini *et al.*, 1991). These models require an inner cavity of 26 AU and a disk mass of $\sim$ 0.45 Earth masses ($\sim$ 35 lunar masses). A similar conclusion concerning the particle sizes is reached by Zuckerman and Becklin (1993*b*), for Vega, Fomalhaut and β-Pictoris. Also, these authors estimate that the total masses of these dust disks, contained in particles with radii $\sim$ 0.3 mm, lie in the range 0.1-10 lunar masses.

3. Other circumstellar disks : detections, images and structures

In spite of careful searches, the β-Pictoris system is so far the only firmly confirmed circumstellar disk imaged in the visible. Nevertheless, many disks are currently detected around other stars using a variety of methods. For instance, infrared images obtained by speckle or new adaptive optics technology are now revealing more and more circumstellar material (see for instance Koresko *et al.*, 1993, Ménard *et al.*, 1993, and the detection of a disk-like structure around the pre-main sequence binary system Z CMa, Malbet *et al.*, 1993). Also, among objects suspected to be surrounded by a dust shell, α-Piscis Austrini (Fomalhaut), τ_1-Eridani, ϵ-Eridani and α-Lyrae (Vega) have IR and millimetre excesses interpreted by circumstellar disks (Chini *et al.*, 1990, 1991). Structures are derived for these disks, with inner radii estimated to 40, 53, 7 and 40 AU respectively for Fomalhaut, τ_1-Eri, ϵ-Eri and Vega. Similarly, IR excesses, photometric variabilities, UV emissions, CO and polarization maps betray the existence of accretion disks around several pre-main-sequence stars (Beckwith and Sargent, 1993, and Basri and Bertout, 1993).

An interesting and original detection of a disk is also provided by the eclipsing component of ϵ-Aurigae, a spectroscopic binary which undergoes a partial eclipse of 2 years, every 27 years. The structure of the eclipse light curve reveals not only a disk, observed almost edge-on, around the companion of ϵ-Aurigae, but also ring structures inside this disk (Ferluga, 1990). The radii and width of these rings (of the order of AU) argue in favor of a thin dust disk with an inner clearing zone, and gaps reminiscent of the structure of Saturn's rings. Interestingly enough, the secondary itself could be a close binary, separated by less than 5 AU (Lissauer and Backman, 1984). Dynamical effects of such a binary on the disk could lead to resonant interactions with the disk (Ibid.).

From a recent observation, Stern, Festou and Weintraub (1993) report that a dust disk may also have been reconstructed at millimetre wavelengths, around the star Fomalhaut. A raster scan made at 1.3 mm from the IRAM station in Spain, reveals a disk-shaped object around the star. The aspect ratio of the disk is $\sim$ 2, and its greatest angular elongation from Fomalhaut is at least one arc minute, i.e. more than 500 AU from the star in linear distance, using a distance of $\sim$ 7 pc from the Earth. This experiment detects cold ($\sim$ 20 K) dust particles, with radii large compared to 1 μm. The total mass of the observed disk, inferred from this observation, would be typically 0.01 to 0.1 Earth masses, comparable in order of magnitude, with the mass of the β-Pictoris disk.

Since this observation has not been fully reconfirmed yet, careful independent experiments are now required to study this object and others, if any.

4. Throwing comets on to stars

Spectroscopic observations of accreting gas on to young stars is an active field of research with recent new results, for example the detection of infalling gas around HD 256 (Lagrange-Henri *et al.*, 1990), around the Herbig Be proto-planetary system HD 45677 (Grady *et al.*, 1993), or around 51 Ophiuchi (Grady and Silvis, 1993). For all these objects, modelling of these spectroscopic observations is in ongoing progress.

Again, the β-Pictoris system has proved to be one of the best documented objects. In particular, UV spectroscopic observations of this star show transient red-shifted absorption lines in the stellar spectrum. These lines are highly variable, on time scales ranging from some hours to some days, and show typical infalling velocities of $\sim$ 30-40 km sec^{-1}, which may sometimes be as high as 300-400 km sec^{-1}. There appears to be periods of "activity" of infalling material (several events per weeks in 1985-1986, or since late 1989), with quiescent intervals, like in 1987 (Ferlet *et al.*, 1987, Lagrange-Henri *et al.*, 1988, 1989, 1992, Norman and Paresce, 1989, Bogges *et al.*, 1991, Beust, 1991). These authors discuss the possible origins of these transient features, favoring infalling material from an extended disk, rather than from a nearby stellar envelope.

Coherent models have been built, in which sublimating comets (typically 10 km in size) can explain the intensity of the various absorption lines, as the comets cross the stellar disk along the line of sight (Beust, 1991 and see figure 2). This raises interesting issues, in particular the possibility of throwing small bodies on to a star. This question is now addressed from a more dynamical point of view.

As pointed out by Beust *et al.* (1990, 1991), Beust and Tagger (1993), and Beust and Lissauer (1994), the systematically red-shifted lines indicate that the comets, if any, are always thrown on to the star on almost parabolic orbits, at roughly the same angle with respect to the observer. This suggests that "showers" of comets are occurring (Ferlet *et al.*, 1993), although their origin remains unclear. A possibility is that a planet is presently perturbing a cloud of comets, through close encounters (Beust *et al.*, 1991). However, a problem associated with such a model is that it requires a high relative velocity during the encounters, i.e. either many comets on highly eccentric orbits ($e >\sim 0.6$), or one planet with an eccentric orbit.

A possibility is that the cometary orbital eccentricities are excited through resonant motion with a planet, and are then thrown on to the star during encounters with a second planet. As pointed out by A. Milani (1992, private communication), a more economical model has also been proposed by Bailey *et al.* (1992) to explain the occurrence of sungrazing comets, like the Kreutz family, in our own solar system. In this model, Jupiter secularly perturbs comets, originally on highly inclined orbits ($i \approx 90°$). Averaging the problem, and keeping only secular perturbations, they show that the energy of a comet, i.e. its reciprocal semi-major axis

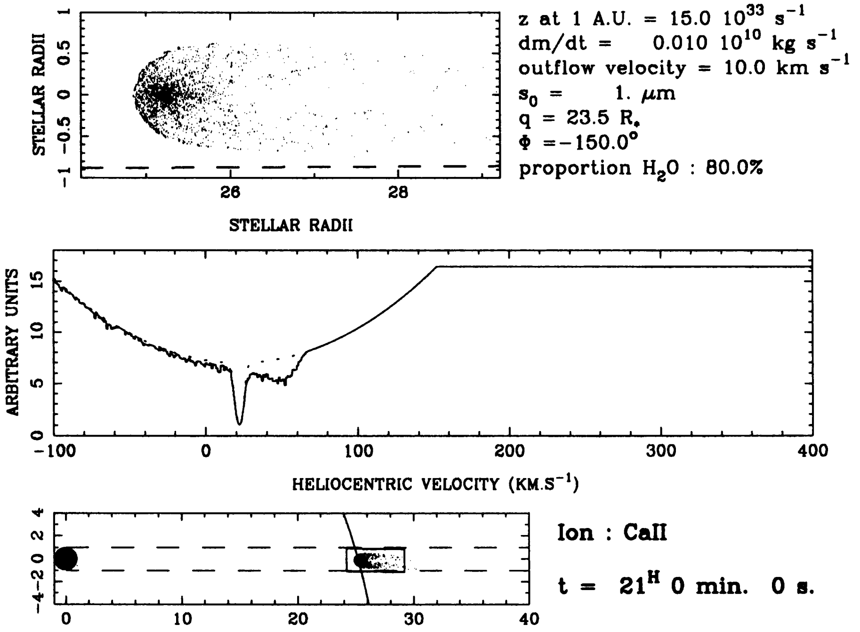

Fig. 2. Modelling the temporal variations the Ca II absorption line of β-Pictoris (from Beust *et al.*, 1990). The top panel shows the Ca II cloud around the nucleus of an infalling comet. The dashed line is the line of sight from the stellar edge to the observer (see the lower panel). The central panel is a synthetic spectrum of the Ca II absorption line, where the wavelength in abscissa has been translated in radial, heliocentric, velocity. The lower panel shows a more general view of the comet orbit with respect to the star (black circle on the left). The box around the comet corresponds to what is shown in the upper panel.

a, is conserved, as well as its angular momentum perpendicular to Jupiter's orbit, i.e. $\sqrt{a(1-e^2)}.\cos(i)=$ constant. There is a third integral of motion (essentially the mean inverse distance of the comet to Jupiter, $< 1/\Delta >$), which makes this problem integrable. The integral curves may go to low inclination orbits ($i \approx 0$) for some appropriate initial conditions. The relation $\sqrt{1-e^2}.\cos(i)=$ constant thus requires that the eccentricity goes to unity as i goes from 90° to 0°, so that the comet becomes a sungrazer. Bailey and colleagues then show that the probability that a comet enters the region of phase space eventually leading to $e \approx 1$ is rather large, so that sungrazing could be a much more common end-state than previously thought. In particular, the number of revolutions necessary to become sungrazer is of the order of 10^3, corresponding a rather short time scale (less than 10^5 years), i.e. at least ten time shorter than the dynamical ejection time scale (corresponding to a close encounter with Jupiter).

It would be interesting to see whether such a mechanism can apply to the case of β-Pictoris, or other stars. In particular, one should address the question of the total number of comets necessary to explain the frequency of events, and the mass of the hypothetical planet responsible for the showers. Another issue is to explain the existence of initially highly inclined cometary orbits. In any event, it seems important to include (hypothetical) planetary perturbations in order to fully describe the behaviour of small bodies around other stars. As we see in the following Section, this may be crucial for detecting planets, either through perturbations on the dust disk or through mutual perturbations between planets in the case of planets around pulsars.

More prospective work is in progress aimed at evaluating the effect of impacting bodies in stellar atmospheres. In particular, planetesimals could be detected while entering the deeper layers of young stars, explaining the flare activity of some of them (Andrews, 1991). More exotic cases have been studied, in which γ-ray bursts are caused by impacts of small bodies on to pulsars (Howard *et al.*, 1981, Harding and Leventhal, 1992). The question of planets around pulsars will be addressed in more detail in Section 6.

5. Dust-planet interaction : detecting a moderately small body

In this Section, we briefly address the question of planetary perturbations on a circumstellar dust disk. This problem may have important implications for understanding the behaviour of dust in our own solar system or in other systems (see the reviews by Dermott *et al.*, 1992 and Sicardy *et al.*, 1993), but also may serve to constrain the existence of planets (otherwise invisible) embedded in dust disks.

Dust disks immediately raise the question of time scales. Even without gas drag or interparticle collisions, μm-sized dust grains decay on to the star within a few million years through Poynting-Robertson (PR) drag (Sicardy *et al.*, 1993). A replenishing source is thus required to maintain such disks. In the course of this decay, planets may have an important influence in shaping the disk, especially by temporarily trapping particles at mean motion resonances. This may be the case both in our solar system (Jackson and Zook, 1989, 1992, Marzari *et al.*, 1991, Jayaraman and Dermott, 1993, Weidenschilling and Jackson, 1993), and in circumstellar disks (Scholl *et al.*, 1993, Lazzaro *et al.*, 1994, Roques *et al.*, 1994).

General conclusions on the behaviour of grains subjected to PR drag and perturbed by planets may be derived from the above works (see also Fig. 3) :

- Even though permanent trappings into resonances are *not* observed in any numerical experiments, the trapping time scale is comparable to the PR drag decay time scale, resulting in a possible accumulation of particles just outside the planet orbit.
- At typical planetary distances (e.g. ~ 20 AU) from a star like β-Pictoris, there is a critical planet mass of $\sim 10^{-5} M_\star$, i.e. about 5 Earth masses $M_\oplus$ (or 1/3 Uranian masses), above which trapping in mean motion resonances is very efficient for several millions of years (even though not permanently).
- Once they escape the resonances, the particles rapidly decay on to the star, due to their enhanced eccentricities in the resonance. This, combined with the long trapping time in resonances, leads to the creation an inner clearing zone by planets with mass larger than ~ 5 $M_\oplus$.
- A moderate (10^{-2}) planet orbital eccentricity can create large scale azimuthal (arc-like) structures in the disk, see figure 3.

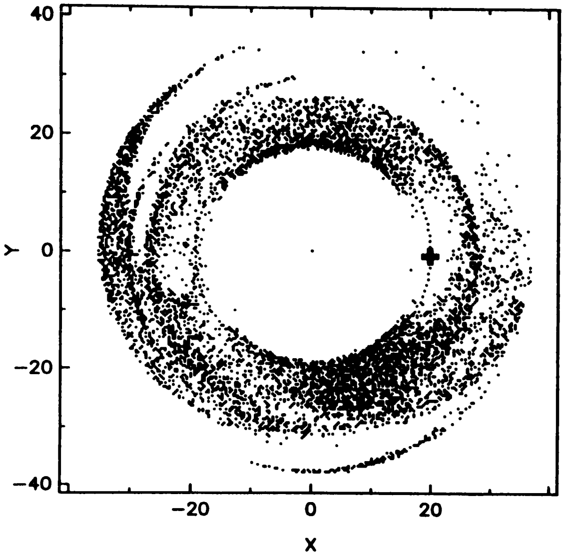

Fig. 3. Pole-on view of a simulated circumstellar disk around β-Pictoris (from Scholl *et al.*, 1993 and Roques *et al.*, 1994). The central star is represented by the dot, and the perturbing planet is at the black square on the right. Motion is counter-clockwise. Cartesian coordinates X and Y are in UA. The planet has a mass of 10^{-4} stellar masses, i.e. about 3 times the mass of Uranus, or half the mass of Saturn. Its orbital eccentricity is 0.01. The motion of 8192 particles is followed on a Connection Machine, taking into account the perturbation of the planet, and the effect of pressure of radiation and Poynting-Robertson drag. The ratio of the pressure of radiation to gravity is 0.3, corresponding to particles $\sim 2\ \mu$m in radius around β-Pictoris. The particles, initially released between 32 and 33 AU, are shown here after $\sim$ 0.6 Myears. Note the conspicuous arcs of material forced by the planet eccentricity. Note also the accumulation of matter ahead and behind the planet, as well as the void of particles around the planet.

Improving observational techniques, both from the ground and from space, could provide high-resolution images of circumstellar disks. It would be important to compare theoretical results against such data. In particular, Jovian or even Earth-like, planets are expected to be sufficiently massive to drive conspicuous structures in these disks (Paresce, 1992, Roques *et al.*, 1994). This would provide an efficient method for detecting extra-solar planets, otherwise too dim to be directly imaged.

6. Planets around pulsars

A planetary companion can be in principle detected through the motion of the star around the star-planet barycentre. Such detection is in practice quite difficult, although sub-milliarcsecond interferometry now yields very promising results (see e.g. Pan *et al.*, 1992).

The Doppler effect on spectral lines from a star directly provides its radial velocity with respect to the observer. Consequently, it may also reveal the presence of a low mass companion through motion of the star around the center of mass. This method has been used to detect a large Jovian planet, or a brown dwarf, orbiting in 84 days, at ~ 0.4 AU around the star HD 114762 (Latham *et al.*, 1987).

Using the same approach, the detection of Earth-like planets around pulsars is a remarkable consequence of the amazing stability of the rotational period P of the pulsar. Typical values for the time derivative, $\dot{P}$, of millisecond pulsars are less than 10^{-15}, and as low as 1.21×10^{-19} for the pulsar PSR1257+12 around which a planetary system may have been detected (Wolszczan and Frail, 1992, and see below).

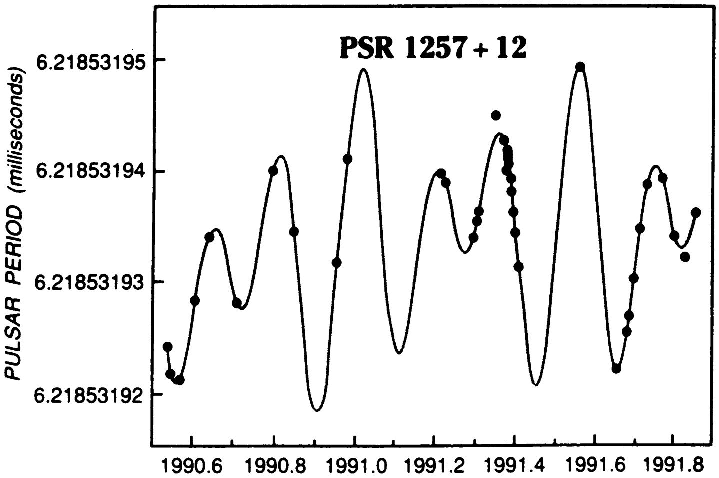

Fig. 4. The motion of the pulsar PSR 1257+12 around the center of mass of the system pulsar + planets causes a modulation of the apparent period of the radio pulses (in milliseconds) with time (in years). The dots represent the data, while the solid curve is the prediction of the model with two planets, as described in the text (Wolszczan and Frail, 1992, from *Sky & Telescope*, Fienberg, 1992).

This stability allows one to detect small modulations of the times of arrival (TOA) of radio pulses from the pulsar, forced by the periodic gravitational pull of small surrounding planets (see figure 4). More precisely, the motion of the pulsar around the barycentre of the system pulsar + companion(s) induces small, but detectable delays and advances of the TOA's, a simple version of the Doppler effect. The periodicity of these time residuals (with respect to a unperturbed pulsar) combined with the laws of celestial mechanics yields the "projected" mass of the companion, $m.\sin(i)$ and its "projected" semi-major axis $a.\sin(i)$, where i is the inclination of the orbital plane of the companion with respect to the plane of the sky. The factor sin(i) obviously arises because the TOA residuals are only sensitive to pulsar displacements along the line of sight.

A first report of TOA modulation was given by Bailes *et al.* (1991), who deduced the existence of a Uranus-like planet around the pulsar PSR1839-10 with an orbital period of 6 months for the planet. As later became apparent, however, the 6 month modulation was actually the imprint of the Earth motion. The latter was inaccurately removed from the observations, due to an offset of 7 arcmin on the actual position of the pulsar in the sky (Lyne and Bailes, 1992, Fienberg, 1992). An independent observation of a millisecond pulsar, PSR1257+12, led to the discovery of a *double* modulation, with respective periods of 98.2 and 66.6 days (Wolszczan and Frail, 1992). The projected masses of the putative planets causing these modulations are 2.8 and 3.4 $M_\oplus$, with projected semi-major axes of 0.47 and 0.36 AU, respectively. The orbital eccentricities are also detectable, with values of 0.020 ± 0.006 and 0.022 ± 0.007 for each planet.

An unexpected (and lucky) confirmation of this detection could be provided in the near future by celestial mechanics. The ratio between the two periods, ~ 1.48, put the planets near a 3 to 2 mean-motion resonance. Then, mutual perturbations of the two bodies may build up over several years, yielding a slow, but large, modulation of the TOA's with respect to a model in which the planets would not interact at all. Such an effect would be undetectable were the planets not in resonant interaction. This slow modulation would provide irrefutable proof of the presence of the two planets and it would also yield the *absolute* value of the planet and pulsar masses, and thus the orbital inclination i, and the absolute values of the semi-major axes of both planets (Rasio *et al.*, 1992).

Malhotra *et al.* (1992), and Malhotra (1993), have shown that for values of $1/\sin(i)$ larger than about 10, the planets are actually in "exact" resonance. More precisely, the critical angle of resonance $3\lambda_1 - 2\lambda_2 - \tilde{\omega}_1$ (where λ is the mean longitude, $\tilde{\omega}$ is the longitude of periapse, and the indices refer respectively to each planet) then librates about 0 or 180°. The orbital eccentricities of both bodies also undergo excursions large enough to be easily detected on the TOA's modulations, over periods of the order of 10 years. However, as analyzed by Peale (1993), the present observations already rule out masses corresponding to values of $1/\sin(i)$ larger than about 4. This author also points out that the accuracy on the TOA's is such that an observational interval of $\sim$ 1000 days is necessary to detect the effect of mutual perturbations between the planets.

An interesting issue raised by these detections, if confirmed, is the possibility of accreting planets around catastrophically formed objects like pulsars (see the review by Fienberg, 1992). This was doubtful in the case of pulsar PSR1829-10, in view of its its estimated young age of $\sim 10^6$ years, given by its spin-down time $P/\dot{P}$. Nevertheless, some models were proposed in which a tiny fraction of the supernova remnant, which fell back around the pulsar, provided material for planetary formation, on a one-million years time scale or less (Lin *et al.*, 1991). Another possibility is that a former companion of the pulsar has been ablated by the latter (Krolik, 1991). The short time scale problem is avoided in the case of the millisecond pulsar PSR1257+12, whose spin-down age is of the order of 10^9 years.

This large time allows for more complex scenarios to be investigated. For instance, Tavani and Brookshaw (1992) propose that the original pulsar vaporizes a stellar companion. The ablated material than spirals outward, forming a disk from which planets accrete over several millions years.

New candidates are now on the list of pulsars with planets. For instance, a sub-Jovian planet, orbiting at about 7 AU from PSR 1620-26, could explain the anomalous spin period second derivative of the pulsar (Sigurdsson, 1993). According to this author, the presence of the planet around the pulsar could be the result of a capture during an encounter with a main sequence star, around which the planet previously revolved.

7. Conclusions

Improving observational techniques reveal complex circumstellar systems, where not only dust but also comets and probably planets, all interact. The increasing amount of data which is going to be collected on these objects in the near future will allow to fill the many gaps existing in our own solar system formation theory. Also, it is interesting to note that the discovery of planets, and in general, cold material, in exotic environments (pulsars, white dwarf, multiple systems, etc...) implies that planetary bodies may exist in situations greatly different from those previously expected. Ongoing observational efforts could thus show that small bodies are rather common in the universe, after all.

Acknowledgements

The author thanks Jean Schneider for providing many references on the various topics considered here, and Mark E. Bailey for a very careful reading of this paper. This work was partly supported by the Programme National de Planétologie.

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