THE OUTER PLANETS – FLY-BY PROSPECTS

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My topic concerns the question, what might be some of the benefits from the fly-bys of the outer planets. Now, if you are going to study the solar system, one thing that you might talk about is its overall chemical composition.

With that in mind, suppose we took all the known mass in the solar system, threw it into a gigantic blender, ran that blender for a while, and then extracted 1 kg. In that kilogram, if it had been well blended, 998.6554 g would have been solar matter, taking up almost the whole kilogram. I have to use that many figures, although they are not accurate, in order to illustrate some of the things that we are interested in later on. If you could identify it, you could then pull out 1.336 g of giant planet matter, which would include all of Jupiter, Saturn, Uranus, and Neptune. If you could separately identify it you could pull out only slightly less than 5 mg for all the terrestrial planets together, not just the earth alone. The moon, of course, would be almost nonexisting, having such a tiny part in it. If you followed my figures I accounted for all but 2.72 mg of the original kilogram – and that would be Pluto (although that one is still uncertain), all the satellites, the asteroids, all meteoroid matter, dust, comets, and so forth. So, if you really want to study the composition of the solar system in any real sense, obviously you must study the sun. But it is also reasonable to be interested in that part of the solar system which is not the sun, but the next level of division. In doing that, let us go through our blending process again, take everything we know about that is not in the sun, blend it together, and then extract from that. If we pull out 1 kg of blended extrasolar matter, the earth would be 2.232 g. All the extraterrestrial planets together without the satellites would be 4 g out of our kilogram. Jupiter, without his satellites, would be 710 g, which is the biggest chunk of the kilogram. We have Saturn with 213 g of the kilogram. Uranus and Neptune, all lumped together, add another 71 g. We add the satellites, Pluto, asteroids, and all that and we get another couple of grams. In other words, Jupiter and Saturn together have 92.3 percent of the extrasolar matter. The giants together, even without their satellites, have 99.4 percent. For example, all of the terrestrial planets lumped together have only 0.4 percent, and this includes the moon, even though the extrasolar matter have only 0.0027 percent of the matter that is not in the sun itself. So in the same kind of sense, I will not argue that you cannot find out very fascinating things about the moon and all that, but it is easy to lose sight of the fact what a small sample of the solar system the moon represents. On a basis of abundance, this is important.

When we go out and launch our fly-bys by the planets, the question, of course, is what the benefits will be. One benefit is obvious and I am just going to mention it briefly. For a long time, we have suspected that we knew the composition of Jupiter. In fact, theoretical predictions were made long ago which said Jupiter was about 80 percent hydrogen; that was at the time when the spectroscopic evidence indicated that first quantitative estimate was only 1 percent of that. But the theory seemed clear. Other theories tried to shake the model and always ended up with that and just argued that the atmosphere of Jupiter was fooling us. It was composed differently but anybody that really looked at the theoretical problems carefully always came up with 80 percent hydrogen by mass for Jupiter. That seems to be what the spectroscopic people have now homed in on and so now theory and experiment agree. I do not anticipate any change in this in the case of Jupiter, and probably little change in the case of Saturn which has less, although there are worries about Saturn.

Now, in regard as to what else is there, a great deal will be learned, but we already know the big bulk of it is hydrogen and the rest of it probably is a large amount of helium. The amounts of more common elements that we know about, such as carbon and nitrogen that are there, are small. But when you go out to explore these planets, when you go into any new territory, you will start looking at this subject closer. What always happens is that you are going to have surprises. In the following, I would like to anticipate some of the surprises that will occur from evidence that we already have. There is evidence that there are changes still taking place on Jupiter and Saturn. I do not mean that these are going to be major and I do not necessarily mean that these are fundamental changes, but Jupiter is certainly a dynamic source. It is some kind of heat engine. The evidence for that, to my mind, is now indisputable. It reflects sunlight with a semicyclic periodicity that, at least in a straight-back direction, has an amplitude of half a magnitude, which is about 36 percent or so in amplitude of its total. In addition to that, strange things have been seen. Sampson, when he did some monumental work on the Galilean satellites, would have at that time gotten by far the most accurate value for the astronomical constant (until radar came in) except he was hampered by one thing. After he had done all the theories and corrected them empirically and predicted eclipse times, the satellites never eclipsed exactly when they should have. Sometimes they were behind, sometimes ahead — indicating that the surface of Jupiter they were cutting into was fluctuating by something like ±200 miles, and this led to an ambiguity in the eclipse times which stopped his accuracy so that he did not have the most accurate value of the astronomical constant when he had to assign a probable error for that.

Another thing has happened since then — a very great shock. When a man named Eropkin was observing the satellite eclipses photoelectrically, he ran into a very strange phenomenon. The satellites would act like they were going into eclipse at distances of several tens of thousands kilometers above the surface. There would be a lowering in their light curve, then it would go back up to almost full brilliance before they would go into true eclipse. This was repeated from satellite to satellite. Moreover, different satellites entering, because of perspective effects, at different places and latitudes on the planet showed the different height in a very well defined pattern as a much more elliptical structure than Jupiter itself has. But the place from where this light pulse came, was itself ellipsoidal in structure — at least, we saw one dimension of it — so something was obscuring the light from the satellites quite high above Jupiter's surface. This is a great deal higher up than the stuff seen by Sampson. I mention the Sampson work only because it has been disputed if Sampson really saw that, by people who have looked one time and did not find it.

Another thing that sort of confirms this is that between 1920 and 1950 something happened to Jupiter's fifth satellite. One of the great crosses planetary physics has to bear is that fashions change; around 1920, people had been taking spectra and photographs of planets and watching them assiduously and then suddenly they quit and turned to other things. Until Sputnik went up and the space program got started here, nobody looked at them anymore. But the measurements of the fifth satellite were discovered by Barnard. He watched it for several years and his observation, as all of his work, was extremely accurate and well founded. Basically, he quit around 1918 because of circumstances beyond his control. Since then some observations have been taken up in the late forties and some more recently in the sixties, but the upshot is that, now that more data are in, something seems to have happened to the fifth satellite sometime between 1920 and 1950. It is about 3 deg in longitude off to where it should have been and there is no possibility for error here. That may not seem like a big angle over such a long time but it is quite obvious if you look at the observations as they go and the plot curves. Whether there was such a discontinuity or not, I do not know. It is interesting, though, that whatever happened to the fifth satellite also happened within the same general time frame that Eropkin saw this obscuring matter, and that one explanation of the satellite's advance in longitude would have been some resisting dust.

There are a lot of other arguments for the fact that Jupiter is dynamic. I do not want to overemphasize this, though, because in a way I think Jupiter is a much safer object for study right now than Saturn. As for Saturn, I am ashamed to confess that for a long time I had ignored some facts that were right in front of my nose. Saturn has what is called an equatorial current as does virtually everything that rotates, and it has an atmosphere. I will return to this in a minute. But Saturn's current is much more marked than others. Saturn's equatorial current rotates at least something like 28 min faster than the currents at the 38 deg latitude. That is a big effect. Its total rotation period is about 10 hours; if you take a half hour off that, you get a major equatorial acceleration.

A long time ago, some spectroscopic work was done on it. In the same way that one measured the fact that Saturn's rings were not measuring rigidly, the man just placed a spectroscope slit on the equator of Saturn and then placed it at various latitudes. From the tilt of the spectral lines we can get the rotational period of that particular latitude. His conclusion concerned the poles, although he did not look at them. Considering the way we have to lay our slit, we would not get any light at the poles. He got, in fact, a 60 deg latitude but that is higher than any observation has ever been. His conclusion was that the poles might be rotating as much as 1 hr less than the equator. If that is so, most of the theoretical work that has been done on Jupiter and Saturn will have to be looked at again very carefully, because that has been based on the assumption that the body was at least partially and to some fair degree of accuracy in hydrostatic equilibrium. But hydrostatic equilibrium requires rigid body rotation. You can put up with some departure from that because you know on general grounds that atmospheres and oceans with energy budgets either from within or without cannot rotate in hydrostatic equilibrium. But 1 hour out of 10 hours is too much to swallow. There are many speculations. One explanation is that Saturn is at the present in the process of collapse, at about 10 percent in radius. It is still doing it and therefore is speeding faster inside than outside. The speedup, to my mind, would feed primarily into the equator and then diffuse to the poles from that source. This would explain that pattern. On the other hand, though, it may be that for some reason that we do not know, the true period of rotation is more like what the poles would be if this work is right. I understand that McDonald in Texas is going to redo this work much more accurately to see if this is so. The spot work generally tends to confirm it, but the spots do not go to high latitudes, and so we do not know what is going on.

I would now like to talk a little bit on one quite definite topic which is common to the earth, the sun, and the giant planets. It is the fact that all the planets that we know about, the Earth, the Sun itself, and Jupiter and Saturn, have these phenomena called equatorial accelerations. In the case of the earth, this has been debated in the past and it has, in fact, been said that it is the other way. I believe that the latest word on that is that the earth really has an equatorial acceleration. This is a bad term, but if we average the wind velocities on the earth's equator over every year equitably and then average them over the years, the average wind speed at the earth's equator is rotating in the same sense as the earth but faster. At first the meteorologists had a negative equatorial acceleration. They said, the average wind at the earth's equator was actually slower than the earth was turning and that it was blowing the wrong way. But they averaged all their data without regard to seasons, and they had a whole lot more summer data than winter data. However, it requires both of them to make the average come out right. The sun has an equatorial acceleration of some sort. We know that its equator, at least, rotates faster than the poles, and it is very smooth and very well defined. As for Jupiter, we have this equatorial current there which rotates about 5 min faster than the rest of the planet. Jupiter has all these other belts that rotate with somewhat different periods but they differ very, very slightly among themselves — never by as much as half a minute. Basically, a crude picture of Jupiter's rotation is that the equatorial belt of about ±10 deg rotates 5 min faster than everything else. The behavior of the other belts is also confirmed by the periodicity of the radio emanations from them. If we believe that the radio period is in some sense the true period for Jupiter, its equatorial current is indeed a fast current, running faster and real. When we come to Saturn, we do not know.

Recently there has been introduced in the field of hydrodynamics a new term that is somewhat dangerous and somewhat analogous to old electrical engineering terms where they used the concept of negative resistance in talking about certain kinds of oscillators. Negative resistance is, in principle, manifest in the laser; in fact, the laser does have negative resistance but that is not what they are talking about here. The hydrodynamicists finally realized that you can have negative viscosities in a real and literal sense, specifically when you have turbulent motions. I will not go into the mathematics here but we have a system called Reynolds stresses which is really not related to molecular viscosity at all except on a much more fundamental level. In the past we have always used those stresses when we talked about a turbulent viscosity and a turbulent diffusion coefficient. These properties are always many, many powers of 10 higher than the molecular properties when we talk about turbulent viscosity. But if we analyze it in detail, because of the correlations and exchange of these packets, in normal situations the Reynolds stresses do act like an ordinary viscosity and they tend to equalize the mean flow motions. There is no intrinsic reason that you can think of offhand as to why these stresses could not, in fact, cause two streams of water or fluids that are going in opposite directions, with respect to each other, to actually accelerate their disparate velocities. Now you may say, "That is not normal, that does not make sense." Some of the measurements that were made on the sun early in the game and detailed analysis showed, in fact, that the eddies seemed to be doing this. I do not really know whether that has stood the test of time or not and I do not really care because such a phenomenon is possible. Even if the sun is not doing it, it does not mean that it is going on on the major planets, although it would be nice to think that all the explanations were the same. But we cannot do that because Jupiter and Saturn have too different a structure even though they both have equatorial currents.

Often in the past and in the present it has been noticed that two-dimensional turbulence often leads to surprises. In turbulence, as a rule and tendency, as everybody knows, if you suddenly cut off whatever it is that is causing it to be turbulent — the energy supply — the tendency is given by the old paraphrase of De Morgan, "Big whirls have little whirls which feed on their velocity, and little whirls have lesser whirls and so on to viscosity." I think I am quoting that right. But, in two dimensions, this may or may not be true. Two-dimensional turbulence may be normal in the sense that what is going on inside when it is in steady-state, if you look at the inner workings, or what would happen if you suddenly cut off all energy sources and watched it decay, it might just be normal in that sense — that bigger whirls are feeding lesser whirls which feed lesser whirls and finally, viscosity dissipates them on the one end. There is a lesser scale of turbulence possible in two dimensions, also in three, where after cutting off the disturbance everything would die just as it is and pretty much independently of everything else. That would be low Reynolds number turbulence, and in that case you would have, after a while, big vortices left, at least big circulations, which would survive, but they would have been there already and they would not have grown.

The other case which I would like to come to is that, in two-dimensional turbulence you can have things going on inside where, after cutting off the energy supply, the reverse would occur, namely, big whirls would tend to coalesce to form yet bigger whirls which would tend to coalesce to form yet bigger whirls. This would be the natural thing to do. Now, what is natural? Natural means, when you really analyze it, that things are in accord with the second law of thermodynamics. And this, as a fluid dynamicist would also say, is the case for negative viscosity — this coalescence of whirls being exactly the opposite of what happens in normal turbulence. The fact that in two dimensions you can have this phenomenon occur where big whirls grow — the tendency is to grow — is in natural accord with thermodynamics. In a paper in 1949, a man wrote very profoundly on statistical hydrodynamics. This paper is not nearly as well known as it should be; in fact, it is hardly known at all even though its author subsequently won the Nobel prize only 2 years ago — not for this work but for his work in the general field of statistical mechanics. The author was Professor Onsager of Yale. He discovered that a system of two-dimensional vortices — if you cut off viscosity, which is legitimate — had equations of motions which could be technically written in what is called Hamiltonian form that with appropriate treatment could be defined as a very convergent Hamiltonian. He treated this system of a finite number of two-dimensional vortices confined to a finite area by the methods of statistical mechanics and concluded that, if the energy per vortex was below a certain amount, the behavior of these strictly two-dimensional systems was normal in that the tendency was for big whirls to break up. This was with no viscosity. In the real treatment of turbulence, in the region where it occurs, the actual viscosity plays no role. But then he went on and he said that if you put so much energy into this system, into the turbulent motion, so that the energy per vortex exceeded a certain amount, big whirls coalesce.

I will not go into any further details. All I am saying is, you may not like these negative viscosities because they go against the grain, but at least in one case, we have a very careful theoretical treatment by a man who won the Nobel prize for statistical mechanics and who says that this is the second law of thermodynamics; some two-dimensional situations will dictate this if the energetics of the system are high enough. I would like to tell you a little bit more about these negative viscosities because they would explain these equatorial accelerations, but they would not tell you why Jupiter is belted, why its velocity of rotation is pretty much constant in belts and then, suddenly, has small discontinuities, then finally gets down to the equator and breaks loose, and why Saturn — which has a fairly sharply defined equatorial current, but not perfectly so — has its rotational period change fairly smoothly above that current, and whether or not it flattens out around 40-some degrees and stays constant being already 0.5 hour faster than the equator, or whether it goes on to the 1 hour difference that would come from Moore's data.

The question of Jupiter's Red Spot has been one of the most tantalizing puzzles in the history of astronomy. In speaking of surprises, this speech was already prepared before I received recent communications on a possible solution of the mystery, but one thing I would say is that solving the mystery of the Red Spot is as easy as Mark Twain said it was easy to quit smoking, namely, that he did it every day. People have solved the Red Spot mystery over and over and the present speaker is not innocent of that because the present rash of so-called "Cartesian Diver Red Spots" rests half on my shoulders and half on Rupert Wildt's because we were the first of the "Cartesian Divers." But that theory was shot down recently by one man with one word and all "Cartesian

Divers" with it. However, it is easy to get theories on the Red Spot but it is not so easy to prove them. I do not really believe that when we get to Jupiter that we are going to be surprised. A lot of things that go on there concern the field of hydrodynamics of rotating fluids, and they are going to bear fruit here on earth.

I do not believe the Red Spot is going to be a surprise. I think that, because it is so outrageous, we have been trying to find outrageously complicated explanations or bizarre phenomena. The kind of thing that makes the Red Spot has probably been going on on earth under our noses all the time. The Red Spot could be something like a hurricane. Ordinary hurricanes are driven by water vapor condensing, which is their heat source; however, that is not going to drive Jupiter's Red Spot. But whether it is cyclonic or countercyclonic does not matter as long as we have some condensing mechanism. Thus, I think that once we understand hurricanes thoroughly, we will understand the Red Spot.

You will say, "What about the fact that hurricanes die?" Well, do you know that hurricanes die? Suppose, for example, when a hurricane is born out in the Caribbean, we could use some imaginary device that would keep it there without interfering with its internal workings — that we had some kind of hurricane swatter that could swat it back to the place of its birth without allowing it to get over land or to go way up over oceans into Arctic waters where it becomes hard to feed on water vapor because the pressure vapor gets low. Would it then die? Do we have any reason to believe that hurricanes die? We know that hurricanes are born in the Caribbean and die there. On the other hand, though, there are hurricanes that start up there and act like they are going to die there and the U.S. Weather Bureau says, "Relax." Then all of a sudden, they rev up again and come in and smash the coast. Well, all of this is contained in some of the most recent theories I know of. One of the very recent theories I am familiar with says that hurricanes are locally stable but globally unstable. Global is a mathematical term borrowed from topology and does not have any direct reference to the globe of the earth, although the way it got into the usage, I guess, was related to the total earth's surface. An object that is locally stable but globally unstable will do exactly what I have said, in principle. It can live indefinitely because it is always stable locally but the elements for its destruction are always working somewhere in the total dynamical structure with which it is involved. They are like glass, for example. Glass is unstable but locally stable, and it lives for a long time. Things that are locally stable but globally unstable can virtually live forever. There is good evidence, to me, that hurricanes would live, occasionally, virtually forever if they did not get over land where their energy supply runs out or if they did not get over Arctic waters. One of them even crossed Mexico once, I believe; it crossed the land barrier, almost died, got into the Pacific, revved up again and, finally, died only considerably north of San Francisco. They do have a tendency to live. Thus, it is hard to shoot down this hurricane idea on the grounds that the Red Spot has been too long-lived to be a hurricane, because if a hurricane cannot wander, it may live forever.

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