PART V

SUMMARY AND OUTLOOK

Friday 3 June, 1140 - 1230

Chairman: K.C. Freeman

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Oort at the telescope - looking ahead to the next symposium?

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THE MILKY WAY: SUMMARY AND OUTLOOK

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HISTORICAL

First let me review the historical discussions presented during our symposium: the papers by Paul, Gingerich, Hoskin and Smith. I was greatly impressed by the power of abstract human thought in its confrontation with resistant reality. On the one hand we see again and again extraordinary prescience, where abstract beliefs based on little or no empirical evidence--like the island-universe hypothesis--turn out to be, in their essentials, true. Clearly, we often know more than we know that we know. On the other hand, there are repeated instances of resistance to the most obvious truth due to ingrained beliefs. These may be termed conspiracies of silence. Van Rhijn and Shapley agreed about few things. But one of them was that there was no significant absorption of light in the Galaxy. Yet the most conspicuous feature of the night sky is the Milky Way, and the second most conspicuous feature is the dark rift through its middle. What looks to the most untutored eye like a "sandwich" was modeled as an oblate spheroid. These eminent scientists must have known about the rift, but somehow wished it away in their analyses. I find that very curious. Other examples from earlier times abound. We all know that the Crab supernova was seen from many parts of the globe but, though it was bright enough to be detected by the unaided eye in daylight, its existence was never--so far as we know--recorded in Europe. It did not fit in with the scheme of things, so it was not seen.

There is absolutely no reason that I know of to believe that this process has ceased. Thus even now there must be many important facts staring us in the face in a blatant and unequivocal way, which we are refusing to recognize, but may soon find to be of central importance. I found myself wondering "What are these facts?". Conversely, from the historians it is clear that much of what is believed to be scientifically accurate by the most precise and sober minds at one time, is thought (or "known") to be incorrect at a later date. Realization of this fact was humbling. And again, there is absolutely no reason to believe that the process has stopped. Which of our beliefs will seem childish at a later date? I have my candidates here. I think the learned

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discussions which we have all endured and some of us even inflicted on others concerning adiabatic vs isothermal perturbations in the early Universe, may be based on theories which will seem hopelessly naive to later scientists. Yet we also learned that not everything which was believed earlier was wrong--the picture of our Solar System has changed in detail but not in essence since the early part of the century. And much of the early progress concerning stars in the solar neighborhood--positions, motions, distances--has withstood the test of time quite impressively. The trick is to tell which material is in which category.

ASTRONOMICAL PAPERS

Now let me turn to the scientific presentations. First the large-scale galactic mass and light models. There seems, for better or worse, to be a developing consensus around models based on a few physical components. Convergence of the mass models of Schmidt, Einasto, myself and J. Caldwell, and others is perhaps an encouraging sign. Certainly the similarities are far greater than the differences. Among surprising features common to this work is that all seem to want, if not absolutely need, a significant dark-halo component ($\gtrsim$ 1/3 of total) within the solar circle.

The most important and presently uncertain data used by the model makers are of two kinds: classical-local and new-distant. In the first category the revived interest in star counts is impressive. The work of observing groups around Strömgren, Gilmore, Hilditch and others, combined with analytical studies such as those by Bahcall, should do two things. First, they will allow us to tighten up the embarrassingly loose constraint on the local surface density, the Oort limit. I think everyone would agree that the total mass within ±1 kpc of the plane, locally, is certainly more than 40 and less than 100 $M_\odot/pc^2$ and probably between 60 and 80 $M_\odot/pc^2$, but we should be able to do better and perhaps soon will. Also our optical studies will tell us if we need other components such as thick discs in the models, and will help to determine properties of other components.

The other really weak point in the models concerns the rotation curve exterior to the Sun where, classically, the 21-cm work gave little information. Evidence presented by Chini (radio) and Freeman (optical) at this conference seems to require that for $R_0 < R < 3R_0$ the rotation curve is flat or rising, consistent with older work by Blitz and others.

The 21-cm work performed here in the Netherlands, largely through the efforts and brilliance of Jan Oort, revolutionized galactic astronomy. After the initial burst of activity there was a pause, but now molecular CO, IR, X- and γ-ray windows have been opened on the Galaxy in the last 10 years and very rapid progress is again to be expected. The data are pouring in now and it will take scientists having the synthesizing power of Oort or Kapteyn to make sense of it all. My own feeling is that we are in the very early stages of such studies.

Direct observations of gradients in various components, from the gas (Burton) to fascinating COS B results concerning cosmic γ rays (Hermsen) to distant tracers such as M supergiants and H II regions, are increasingly reliable and important and sould ultimately (but not for the foreseeable future) allow us to test in detail our ideas on galactic evolution with information difficult to obtain in other systems. This subject was treated on the last day, and moderately good agreement between theory and observation already exists. Here I want to stress the obvious point that we are gaining in power enormously as we are able to view the Galaxy at wavelengths to which it is largely transparent.

It is logical to turn at this point from the large-scale studies to one particularly interesting part of the Galaxy, and especially to Jan Oort's exciting tour through the Nucleus. There is little I can add by way of review but it is perhaps worthwhile to note a few points that seem to me specially significant. Both the compact radio source and the hard X-ray source now are seen to be unique in the Galaxy. Are they the same thing, and, if so, what? The questions were sharpened. The discovery of the apparently spiral-like features at several wavelengths, especially through recombination-line work, allowed one to make a plausible interpretation of the hitherto baffling Ne^+ data, but I remain as confused as ever. I would not argue against a 10^6 $M_\odot$ black hole at present, but neither would I argue for one. We still do not know enough. I was left with one very simple question. If we could strip away all of the exciting stuff from this region and only look at the old stars, as we can in Andromeda, what would we see? What is the "core radius" of the old stars: is it $\lesssim$ 1 pc, 10 pc, or 100 pc? How big is the potential well, the room within which all these dramatic events are occurring?

Let me now leave the Galaxy and turn to comparison with other galaxies, to the fine papers by Young, Beck and Reich, Elmegreen, and the comparisons with our big brother M31 by Hodge, Brinks and Stark, which were very illuminating. We are becoming mature and are developing a realistic view of where we stand in the world of galaxies. We are no longer the only, or even the biggest, but a rather ordinary-sized Sc spiral. I must admit that I found myself a little disappointed; couldn't we at least be as big as NGC 4565? The regularities that are beginning to be found are impressive. But in most extragalactic (non-optical) studies the resolution available at present just barely allows us to note such features as spiral arms or central holes, and it is clear that detailed study of other galaxies is a field in its infancy. Optical analyses, not presented here, are also making great strides at present.

The situation concerning the mass of the Local Group has not changed in an essential way in over a decade. The paper by Lynden-Bell confirmed that we know or firmly believe it should be measured in units of 10^{12}, not 10^{11}, solar masses, but we have little clue as to where the mass is and no knowledge at all as to what it is. The best current candidates, moderately massive ($\sim 10^{6.5}$ $M_\odot$) black holes, strange particles (massive neutrinos) and low-mass stars, are all possible but none particularly likely.

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The problem of spiral structure I found to be very depressing, not, as one might expect, due to its resistance to theoretical attack but, on the contrary, because of our successes. I shall explain my feeling by relating a dream. Following the pioneering work of Lin and collaborators, Toomre, and others, I believe that we really do understand this phenomenon. In fact I couldn't restrain myself during a recess from explaining to Frank Shu how I really understood the origin and maintenance of spiral structure. I proceeded to stitch together a theory. Of course it had gravity, but it also, of necessity, included the fact that star formation produces star formation--necessary since that is seen to be true. And above all, it required gas dynamics as an essential ingredient. Gas, dissipational, will always cool (in absence of supernovae) until the system is driven unstable and then, as Shu had mentioned during the discussion yesterday, dissipation will limit the instability as well. I commented that I am actually working on this problem with Len Cowie and Scott Tremaine. Frank Shu's answer to our proposed model was "Of course, we all agree, everyone in the field knows all that". Somewhat depressed, I went home for an early nap, in which I dreamt that I was blessed with an army of graduate students each one more eager, intelligent and industrious than the last. Then with this army, and unlimited access to computer time, all the relevant physics was put into the computer model. It took a year to get the bugs out but then, when the first run was complete, voilà! Out come pictures representing at every wavelength real spiral galaxies. By suitable adjustment of knobs every type of galaxy can be made. What a happy dream.

Success!? Perfect understanding of the phenomena. Peace and understanding will reign.

Of course I did not understand the pictures in the incredible detail provided by this wonderful code, so I gave them over to the observers to study. Some found trailing two-arm logarithmic spirals, other one-arm leading spirals. The theoreticians were not better. Each argued, with great logic, that the input of a particular bit of physics was essential to success. And each argued that other elements I had used were really trivial, inessential. The dream ends in chaos with cries and shouts, grown men fighting over control of overhead projectors, etc. I leave it to each individual to draw whatever conclusion he or she may wish from my dream. Mine was that we, in fact, collectively do understand this problem but that the solution is an unappetizingly complicated mess, and the will to simplify what is intrinsically complicated shall drive us to exhaustion. A depressing conclusion.

Slightly more hopeful to me were the theoretical papers of Wielen and Lacey, addressing the far simpler problem of the growth of the velocity dispersion of disc stars. Here we do not know the answer, but there is every expectation that we will understand the answer when we find it. My own bet would be on item (3) of Wielen's list, puffing-up of the disc due to spiral, tidal and other instabilities and perturbations. Carlberg's simulations seem to show this nicely.

Before going on to the future, I will give you one answer to the question I asked earlier of what it is that is in front of our eyes but which we are refusing to notice. My candidate answer is bars. M31 clearly has a bar. I think that our Galaxy has a bar. LMC has a bar. Ken Freeman tells me that SMC and NGC 205 have bars. In almost all members of the Local Group of galaxies bars are seen. Yet this fact never entered any discussion presented here. Even when C.C. Lin described Yuan's work on bar-driven spirals, the spiral was seen in the picture but there was no bar. Could this be a severe omission? Could formation of and effects due to bars be somehow vital, not trivial features? Perhaps.

THE FUTURE

I have already mentioned several of the areas where I believe progress is to be expected. The collection of observations made at many wavelengths (to which the Galaxy is transparent) and coordination of observations of many different types of object is likely to yield rapid progress. But collection of data by itself does not provide understanding, and some hard and some inspired thought will be necessary to produce an intellectually coherent picture. On the theoretical front the computer looms up over us, casting a bigger and bigger shadow. Our giant and exponentially growing helper has become indispensible. With this brute it seems we can do anything, and if not now then soon, with the next factor 10^1 or 10^2 in computer power. But we haven't yet come to terms with the monster, and there may be a contest down the road to see who is to be master.

Let us look further ahead, beyond the immediate and even the foreseeable battles. If I may change my metaphor, will there always be more to learn or will the galactic fishing hole eventually be "fished out"? With all the big problems solved, will we have to fish longer and longer to catch solutions to smaller and smaller problems? Logically that seems possible, even likely. But history teaches us otherwise. There was a synthesis reached with publication of Stars and Stellar Systems, Vol. V, edited by Blaauw and Schmidt, two gentlemen eminently in the tradition of Kapteyn's science. It is interesting to think how far back that book was published--1965, almost 20 years ago. And students reading that book (which I still assign to my classes) might be excused if they thought that we only had to nail down the Oort constants, get better galactic tracers, etc. to understand the Galaxy.

The two biggest current puzzles of galactic astronomy did not even appear, I believe, in that volume. These are: what is the nature, distribution and amount of dark matter, and what is happening in the galactic center? If new problems of that significance continue to arise at this rate, we will not soon fish out the galactic fishing hole, and I hope we can look to our Dutch brethren to continue to supply us with the world's most expert anglers-- in the Kapteyn tradition, ingenious, persistent and precise.