VIII

SUMMARIES

SUMMARY : OBSERVATIONAL VIEWPOINT

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The organizers took advantage of my position as an outsider to much of the work which has been discussed at this symposium when they assigned me this task, thinking that my ignorance would keep me unaware of the indigestion which would result from trying to summarize everything on the menu which we have had in front of us for the past 5 days. I am more familiar with work on our own galaxy, but it does seem to me that IAU Symposium No. 100 fits perfectly into the series of meetings which the IAU has sponsored in encouragement of work on the Milky Way. This series began in 1953 with IAU Symposium No. 1 held in Groningen and entitled "Co-ordination of Galactic Research". I expect that this symposium will serve to co-ordinate extragalactic research in similar ways: I say this because of the impression formed during this week that the study of normal galaxies is experiencing a period of consolidation, when there is a willingness to agree on issues, and when these issues are mature enough that co-ordination of work is possible. Do I correctly perceive that consolidation means that the field is not experiencing the chaos associated with breakthrough? For example, I don't think that this symposium experienced an analogue to the introduction of the brand new Westerbork HI maps experienced at the Besançon meeting of 8 years ago, and it is a year or two too soon to expect comprehensive work from the VLA line system.

The tone of consolidation was set on the first morning by Rubin's plaintive hope that the non-luminous mass would turn out to be "something we can be comfortable with", such as low-mass stars. Her talk, and Bosma's which followed it, stressed several points which recurred throughout the meeting, and which established recurring themes: 1) rotation curves are flat (or rise) over the optical image, and 2) this is a general property shared by field and cluster galaxies. Bosma extended these general, and by now familiar, conclusions with other, also familiar, conclusions:
1) HI rotation curves extend to greater radii than optical curves, and
2) they are also generally flat over the entire observed extent.

Bosma carefully described the HI asymmetries which have to be accounted for before one can trust these generalizations. Asymmetries

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abound, due to spiral arm motions, bar or oval distortions, warps, and the sort of structural asymmetries and kinks that led us to be reminded often during the meeting that spiral rectification in the manner of Danver rarely works well. These asymmetries plague even such familiar galaxies as M31 and M33, both of which are probably warped, and M101 which is lopsided, as is the inner part of M33, and as is, quite possibly, our own galaxy. Simkin illustrated a different kinematic asymmetry with NGC 2903, whose optical center is displaced from the rotational center.

The structural and kinematic asymmetries made Bosma caution us to be careful with HI rotation curves: the envelope of the measured velocities might represent some characteristic of the galaxy other than rotation in circular orbits. Nevertheless a question from the audience forced Bosma to admit that there is "no solid evidence yet for a falling HI rotation curve". He mentioned curves which appear to fall: NGC 891 is asymmetric, and NGC 5907 is warped such that simple geometry probably does not suffice when deriving the kinematics. Warps were established as a theme of this meeting when Kennicutt provocatively claimed that the number of warped and distorted galaxies is equal to the number of galaxies studied. Bosma stressed that the HI warps are kinematic as well as structural. Although they occur in a variety of complicated forms, these forms often share the property of starting at the optical edge of the galaxy. He presented a counter example of his own, however, in UGC 2885 where the HI follows distorted optical arms to large distance.

Thonnard summarized work by him, Roberts, Rubin, and Ford on some 60 Sa,b,c spirals. Asymmetries are shared by Hα and HI and commonly occur over large portions of the disks. Shostak discussed a kinematic study of the warp in IC 10, an apparently messy, nearby, irregular barred magellanic galaxy. The kinematics of that galaxy show enough systematics when observed with 8 km s^{-1} resolution at Westerbork to allow study of a face-on warp.

IC 10 also shows a hole in the HI distribution towards its center. Central deficiences of HI in the cores of galaxies have become familiar. Such holes - our galaxy and M31 are prototypes - are being put into a new context by the studies of comparative gas morphology reported by Solomon and Young. These new studies are centered on extensive radio observations of the CO line. Their groups have independently mapped the CO distribution in several dozen galaxies. The data show that 1) annuli similar to the one found in our galaxy are found in many other galaxies; 2) CO does not follow the HI distribution, although in the region of overlap the HI and CO kinematics are similar; 3) CO does follow the blue light distribution over 2 orders of magnitude in CO and luminosity; 4) the surface density of H_2 dominates HI in the central regions of high luminosity galaxies; and 5) the surface density of H_2 is approximately equal to that of HI in the central regions of low luminosity galaxies.

Young pointed out that high luminosity Sc's have no CO central holes, but that Sb's with large bulges do have holes. NGC 253 has a hole like our galaxy's. Young indeed suggested that NGC 253 is a galaxy similar to ours. Both galaxies might well be barred, a point van Albada had in mind when he asked if oval distortions might be responsible for the central CO deficiences.

de Vaucouleurs asked that someone present soon the convolution which would show what the Milky Way's HI and CO radial distribution would look like from some Mpc distance. For the HI, that would be easy to do, but for the CO, it would require careful consideration of antenna beam characteristics and beam filling factors. We can imagine circumstances where the hole in our galaxy would be overlooked. Results from our galaxy, particularly on the distribution parameters of the molecular cloud ensemble, can be very useful in interpreting the CO data now becoming available for other galaxies.

These distribution parameters are bound to be important in a different context. Numerous discrete objects of some 10^6 $M_\odot$ embedded in the ISM would govern many aspects of the medium. The same can be said for the holes in the HI report often this week, for example by Shostak in IC 10 and by Bajaja in M31, and for the Hα bubbles reported by Marcelin in NGC 5128. Masses of 10^6 are involved, and expansion motions of some 20 km s^{-1}. These constituents must be important even on a global scale. Norman emphasized this in his review of galactic theory. Perhaps at this meeting it would have been useful to have had a review specifically on the morphology of the interstellar medium in spirals.

Interpretation of the correlation of the radial distribution of CO with that of blue luminosity in late-type galaxies generated much animated discussion. Does this correlation mean that H_2 density follows blue light, and that the star formation rate follows the 1st power of H_2 density? This was suggested, but Blitz countered that the CO-to-H_2 conversion involves many uncertainties. In M31, the blue light follows the metallicity, so that relation of CO to blue light might be a <u>metallicity</u> dependence, not a <u>density</u> one. Liszt remarked that the correlation might also reflect <u>temperature</u> because of the expected heating of CO in the interior of high luminosity galaxies. More study in our galaxy could guide us on this topic, too. Kennicutt remarked that in any case blue luminosity is not a good measure of the star formation rate.

Manchester presented the impressive results of the first southern CO survey. Arguments raging amongst members of our own galaxy's CO guild regarding the degree to which the CO is confined to spiral arms might be guided by work in nearby galaxies. Rydbeck said there is no arm/interarm contrast in M51.

Solomon expressed some scepticism that Kutner's work correctly shows the amount of CO emission beyond the Sun. But there can be no doubt that the HI dominates in the outer galaxy. Blitz discussed this for our own galaxy, and Sancisi for other galaxies. In general, HI extends furthest out of all observed components. The poster of Wever showing the Palomar-Westerbork survey of radial distributions of light, color, and HI mass was very relevant to this conclusion.

Sancisi compared outer-galaxy optical and HI profiles. Often (e.g. NGC 4564, 5907, 628) he finds an exponential fall-off to a sharp truncation of the optical disk, just where the HI shoulder starts and continues to much larger radii (the HI in Mkn 348 extends to 5 times the optical extent). Sancisi speculated that a critical radius separates the region of star formation from the HI galaxy. Also, the warp or unusual HI kinematics would begin at this critical radius. Casertano presented such a model for NGC 5907. Verification of Sancisi's idea requires searches for warps in the outer disks composed of old stars. Wamsteker reports optical counterparts of the warp in M83, extending to some 40 kpc, although this might be an encounter distortion. Trully remarked that our own galaxy's warp begins inside the Holmberg radius; I find it curious that we still are not sure if the stars in the outer disk of our own galaxy follow the HI warp.

Blitz gave a general review of the HI distribution in the outer Milky Way. According to his work, the rotation curve rises above 300 km s^{-1} at R $\sim$ 20 kpc, with the most important source of error residing in the possibility of motions in non-circular orbits. To me the most valuable uses of the outer galaxy HI lie in the availability of the $<z_{\frac{1}{2}}>$-distribution as a function of R, and, although it also has not yet been derived, of the variation of σ_v with R. Blitz concludes from the z-distribution that the HI cannot be confined by the observed mass: the non-luminous mass (80% of it) must lie in a spheroidal distribution.

van der Kruit emphasized the need for measurements of $<z_{\frac{1}{2}}>(R)$ and $\sigma_v(R)$ in other galaxies. His work with Shostak on several galaxies finds $<\sigma_v^2>^{\frac{1}{2}} \sim$ 7-10 km s^{-1} and $<z_{\frac{1}{2}}> \sim$ 300 pc, with the force term requiring in NGC 891 that one third of the mass reside in the disk interior to optical termination, and two thirds in a halo of necessarily dark mass.

If the symposium were to have voted, I suspect a majority would have resolved that 1) flat rotation curves imply dark mass, 2) $<z_{\frac{1}{2}}>$ and σ_v imply that the dark mass resides in the halo, and 3) M/L rises in the outer regions of spiral galaxies. But the vote would not have been unanimous, and the arguments of the dissidents need to be given very careful attention. For example, Tully remarked that accretion of high angular momentum material might give the apparently flat curves, without much dark mass. Observations should be able to resolve this; the outer boundary of our own galaxy is remarkably well defined, with no obvious important perturbations. Kalnajs' remark that he can model optical curves to large distance with a constant M/L was made casually, but was heard by all. I do not know how to respond to it. Certainly I do not know how to respond to Bekenstein's suggestion of non-Newtonian dynamics at low accelerations. But I feel that no rebuttal has been made to the flat HI curves at very large distance, or, as Blitz reminded us, to the globular cluster distribution in our galaxy at very large distance. Until we know better, the problem of non-luminous mass remains.

It might seem trite in a symposium on kinematics to say that the principal observational need centers on more measures of velocity fields and dispersions. It is nevertheless true. Kalnajs emphasized the importance of σ_v measures not only to determination of the mass distribution but to theories of spiral stability. Collisions of clouds might preserve spiral structure larger than in a gas composed of stars only. Carlberg's age v. σ_v theory could be tested. According to the theory, star formation leads to patterns of low σ_v which provide instabilities giving a short-lived spiral.

We heard rather less than I would have expected on observational predictions of the stochastic star formation theory, or for that matter, of the density-wave theory. Feitzinger claimed that stochastic star formation can generate realistic morphological sequences. Binney recalled us of Schweizer's demonstration of a smooth underlying red component, which the stochastic theory might find awkward. Norman concluded similarly that the coherence length is not long enough. Lynden-Bell reminded us of repeating structures, and Tohlin reminded us of bars: both are difficult for the stochastic theory. In favor of the theory, van Woerden mentioned large complexes in M101.

More observational work on the cross-sectional distribution of spiral arm tracers seems called for. The need for such work was emphasized by Allen, who speculated that Taurus will show that the kinematics of HII will differ, as predicted by the density-wave theory, from the kinematics of HI.

Three themes kept returning: warps, halo-mass, and bars. Toomre in his review of theories of warps asked if warped galaxies are also flare-edged (a propos of a flag-flapping instability) or if they have bars. These are questions which observations should soon be able to answer. Sandage remarked that M31 and M33 have warps but no halos.

Kormendy's review emphasized also the need for velocity fields in bars. His work to get the stellar velocity dispersion in bars represents a major and difficult program. Apparently the velocity dispersion in the disk around bars is hot, and this region of transition shows a dip in the rotation curve; clearly the bar potential rotates differently from the galaxy-at-large and will stir the galaxy up. The dust lanes on the leading sides of only pure bars are not yet understood, but as Kormendy emphasized, must be a key property.

Lindblad reported on work on NGC 1365 which showed that the velocities are perpendicular to the bar. In a poster on NGC 1365, van de Hulst showed in VLA data concentrations of HI on the edge of the bar but not on dust lanes.

Illingworth reviewed a major observational effort on elliptical galaxies. Some of his points: 1) some ellipticals have rising rotation curves, 2) some have dispersions approximately constant, meaning M/L probably rises outwards, 3) many ellipticals show dust and gas on the minor axis, implying that more than one kinematic system is present (this is a general problem, also for our galaxy, and was confronted in this symposium by theories of response to a triaxial potential), and 4) galactic bulges are different from ellipticals (photometry required), because bulge rotation velocities stay constant with z, whereas in elliptical the rotation velocity falls slowly into halo.

Dressler has studied the luminous bulges of S0's: they rotate rapidly, not as equivalent E galaxies. Although most S0's occupy the same region of the Fisher-Tully diagram as spirals, some 10-20% lie far outside that region, implying that those S0's are not disk systems like spirals. Dressler urged caution in inferring kinematics from the optical morphology of many S0 galaxies. Nevertheless, Sandage argued that S0's, and smooth armed Sa's, are part of the Hubble sequence. S0's have a high disk surface brightness; Sc's have a low disk brightness. According to Sandage, S0's can not be formed by stripping Sc's of gas. I found the Westerbork results presented by van Woerden showing HI in enormous rings enveloping some S0's among the most important results presented at the symposium. The HI distribution extends to some three optical diameters.

Tully presented an extragalactic analogue to the HR diagram, based on hopefully distance-independent parameters of color and magnitude. Rubin wondered if M does not depend on luminosity, however, not just on velocity.

Knapp's discussion of gas in ellipticals emphasized the new result that the gas is distributed in clumps, and includes cold HI and molecular material. The VLA results on Cen A reported by van Gorkum show absorption lines very near the nucleus, with an accretion rate of a few .1 $M_{\odot}\ yr^{-1}$. Do we see the radio galaxy being fed? This result, and also Gottesman's results on the elliptical companions of M31 which show HI offset from the symmetry of the distribution light, make it hard to imagine that the gas does not come from outside the galaxy.

Ulrich's discussion of the ionized extended gas in normal E's was also relevant in this regard, especially the result that there is no correlation between the optical axis and the velocity field of gas. She likewise concluded that some of the gas must come from outside.

We had a spirited review of mergers by Schweizer, backed up by a handsome collection of photographs of ellipticals. Schweizer has searched for prototypes of mergers in advanced stages; he chooses to reject as prototypes pairs of galaxies, like the antennae, which represent encounters rather than mergers, and also chooses not to include multiple-nuclei cD's, claiming evidence based on their color is unreliable and that the components of cD nuclei may differ in their velocities by 100 km s^{-1}. In Schweizer's view the best examples for mergers are Fornax A (which he describes as an elliptical in a very extended envelope), Cen A (described as a dust disk in an elliptical), and NGC 7252 (described as two disks, each with independent kinematics).

The signature for these and other Schweizer mergers includes ripples and tails. The tails we are to understand according to the Toomre gospel.

The ripples were remarkably well simulated in Quinn's movie showing the response of a disk to capture by a central potential representing an elliptical.

Schweizer would have about one quarter of all field ellipticals have ripples and would have many (all?) field ellipticals have accreted disks. Several points were made in the discussion and in subsequent contributions which are relevant to, and difficult for, this point of view. Sandage challenged the view that ellipticals commonly formed by mergers on the basis of observations that 1) the density of field galaxies is too low, 2) the velocity dispersion of the galaxy ensemble is too low, and 3) ellipticals exist over a range of 12 magnitudes in Virgo, implying a range 10^6 in mass, and making too extreme demands on the Schweizer scenario. Sandage prefers to consider E's as part of the Hubble sequence.

Special problems of merger in the specific case of Cen A were pointed out by Marcelin, based on Hα interferometry, and by Taylor, on the basis of Taurus interferometry. Both investigations have impressive velocity resolution and both maps show a very regular velocity field. The Taurus data were modelled by a rotating disk, perhaps warped but otherwise well-behaved in ways that a merging disk might not be. Rubin remarked, however, that she has observed a pair of galaxies whose rotation curves fall through zero, indicating a measure of interaction.

Freeman's discussion on globular cluster systems held some surprises for me. The metal-rich clusters in M31 rotate as rapidly as the HI! In our own galaxy the rotation of the cluster system is much slower, and in the LMC the system is highly flattened.

The Scientific Organizing Committee of Symposium 100 put together a program which admirably incorporated the current activity in studies of the kinematics and dynamics of normal galaxies. It is tempting to speculate on the advances which we might anticipate hearing discussed at a meeting on this topic held a few years hence. It seems to me that we might well hear of substantial advances based on new instrumentation, on mature instrumentation, and on persistence in following current major studies. Regarding new instrumentation: I found myself especially impressed with the potential described by Atherton of the Taurus Fabry-Perot interferometer. This instrument will map out Hα spectral line profiles channel by channel with a 1/3 Å filter bank. The velocity resolution of 10 km s^{-1} will provide extremely valuable kinematic fields for galaxies, bars, planetary nebulae, and supernovae remnants. Regarding mature instrumentation: I think especially of HI line work which we may expect from the VLA. At this meeting such work was represented only in posters but included the remarkable maps of M81 by van der Hulst and van Gorkum, and of M31's satellites made by Gottesmann and Hunter. Regarding advances due to persistence: I was especially struck by the enormous wealth of details contained in the Westerbork HI survey of M31 carried out by Brinks and reported on by him and by Bajaja. A program of this magnitude is a long-term undertaking, but it will have provided in the near future for M31 the same sort of spatial and kinematic resolution as is available now only in the standard surveys of our own galaxy. An evolutionary development will thus be brought full circle, with problems formulated but never solved in our own galaxy now available for study under many more favorable conditions in other galaxies.

DISCUSSION

DJORGOVSKI : In your talk you asked whether our galaxy has a stellar warp following the hydrogen one. I have looked into this question following suggestions from Harold WEAVER and Leo BLITZ. The aim was to see if it would be possible to detect the stellar warp in the infrared. I have made a simple galaxy and stellar population model, and integrated the direction of the HI warp. The results indicate that it may be (marginally) possible to detect an excess of IR light there, but the uncertainties are very high. I then looked at NASA IR survey maps, and indeed there seems to be something there (galactic longitude about 80, latitude 5° - 10°), but it is highly uncertain whether this is due to foreground sources or to the warp.