DETERMINATION OF GALACTIC SPIRAL STRUCTURE AT RADIOFREQUENCIES

H. S. Liszt
National Radio Astronomy Observatory

ABSTRACT. We consider some results of attempts to trace the pattern of galactic spiral structure in HII regions, HI, and CO. There is really no adequate method available for solving this problem, a fact reflected in the lack of consensus regarding the "correct" spiral pattern. The newly-begun process of deriving galactic structure in CO seems to be recapitulating the history laid down by HI observers.

I. INTRODUCTION

We have at our disposal a variety of instruments capable of penetrating to the farthest reaches of the Milky Way, and use of this equipment for the purpose of deriving any large-scale galactic spiral structure is a major field of astronomical endeavor. The motivation for this work is strong and its goal a highly desirable one. Once having achieved it, we could combine very detailed observations of the physical state of the interstellar medium with a suitably detailed picture of the disk kinematics and dynamics to reveal the processes whereby the Galactic System evolves and is maintained over its lifetime.

Nonetheless, there exists a wide spectrum of views regarding how well we have done in deciphering galactic structure to date, or indeed, how well we shall be able to do in the future. The history of charting the galactic spiral pattern is a curious one, as structures have been found even when the observations employed were fallacious or when the spiral tracers "observed" do not exist in nature. One example of the latter phenomenon is the pattern derived for stellar rings (Figure 1) by Schmidt-Kaler and Isserstedt (see Schmidt-Kaler 1971), and another more recent example may be the "arm-like concentrations" found in weak-lined CO clouds in the outer Galaxy by Kutner and Mead (1981). Crampton (1971) has shown that stellar rings are not physical associations and Solomon, Stark, and Sanders (1983) have not been able to detect and confirm the vast majority of Kutner and Mead's sources.

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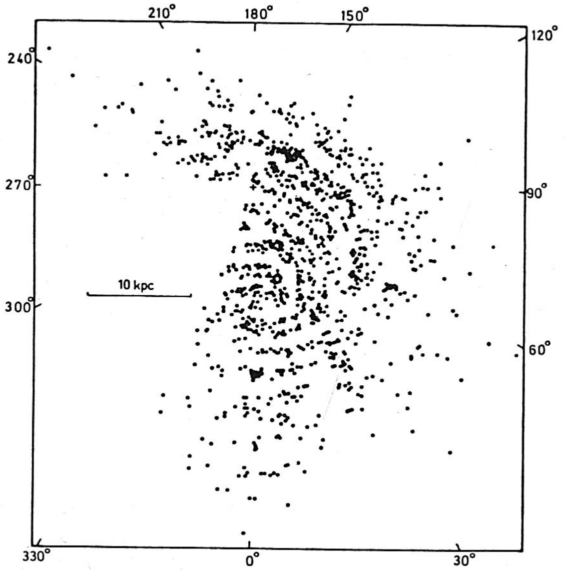

Figure 1. The spatial distribution of stellar rings from Schmidt-Kaler (1971). These objects are no longer believed to be real, but evince a clear spiral pattern.

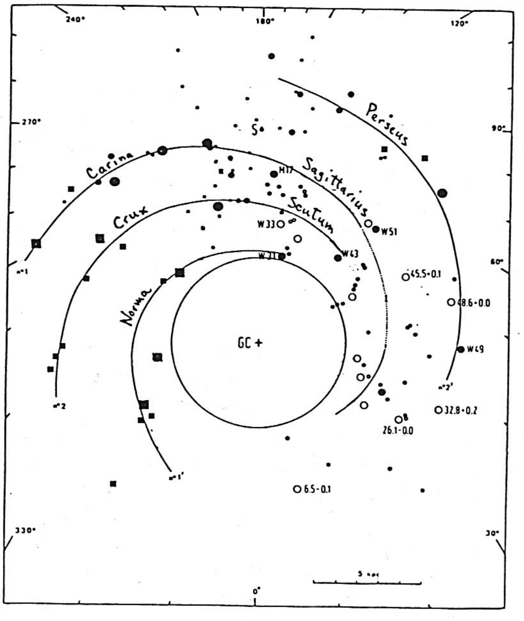

Figure 2. The spatial distribution of HII regions: data from Georgelin and Georgelin (1976) at longitudes above 60° and from Downes et al. (1980) elsewhere. The original spiral pattern drawn by the Georgelins is shown.

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The problems inherent in tracing spiral patterns from within the galactic disk are not especially subtle, notwithstanding the fact that they are frequently ignored in greater or lesser degree. We lack perspective and often must settle for determination of a radial velocity and ambiguous kinematic distance when what we desire is an accurate heliocentric distance. All galactic tracers have an intrinsic velocity dispersion and they are often too widespread and confused in our observations to isolate the contribution of any given region or source. Only the mean circular-velocity field is known across the galactic disk, while significant perturbations of this motion occur frequently and especially in association with spiral arms. The purely kinematic patterns observed in HI and CO are sufficiently complicated that there is no consensus as to which loci in position-velocity space actually constitute single, connected features.

Here we summarize some of the many, many efforts which have been directed at deciphering galactic spiral structure. We concentrate on radiofrequency measurements and on tracers with some degree of kinematical information, neglecting the galactic continuum. We also neglect recent developments concerning the spectacular flaring, warping and corrugation of the outer galactic disk (Henderson, Jackson, and Kerr 1982, Kulkarni, Blitz, and Heiles 1982), and the peculiarities of the innermost regions (Burton and Liszt 1983), all of which will be discussed by others at this Symposium.

II. HII REGIONS

In the inner Milky Way, HII regions are especially useful spiral tracers because their kinematic-distance ambiguity may sometimes be resolved through use of absorption spectra, because they tag some molecular clouds by causing high CO-line temperatures, and (most importantly) because most everyone seems to expect them to show a clear grand design (but see below). Optically, of course, actual distances are available near the Sun and in the outer portions of the galactic disk.

Shown in Figure 2 is the inferred distribution of HII regions taken from Georgelin and Georgelin (1976:GG) at longitudes above 60° and from Downes et al. (1980:DWBW) elsewhere (a similar but more comprehensive diagram is given by Forbes 1983). The dataset of GG has been modified slightly by correcting several errors in resolving the kinematic-distance ambiguity as noted in the footnote to their paper and in the tables of Lockman (1979); as well, we have removed a few objects whose velocities are cited by Lockman as being highly unreliable. Plotted in the Figure are the original spiral patterns put forth by GG, and inspection (see also Figure 4 of DWBW) will show how substantially they must be altered to fit the newer northern dataset. No matter what pattern is fit to the data, very long segments of the supposed arms will be devoid of detected sources. As remarked by Forbes (1983), quite a few beads must have slipped off our galactic string.

Spiral features in Figure 2 have been labeled with their usual names, and it will be seen further on that the tangent points of the GG arms also appear in several other measures of large-scale galactic structure. One of these is significant perturbation of the observed maximum line-of-sight velocity. But this phenomenon, when itself taken as a signpost of spiral structure, implies that the pattern which has been derived is seriously defective. Essentially all the HII regions found at large distances are radio objects and have been placed in galactic perspective using the mean axisymmetric rotation curve. Unfortunately, this rather idealized function does not provide a detailed prescription for accurately locating any given region, and is especially inadequate near a spiral arm. All claims to the contrary aside, large-scale deviations from the mean pure circular motion will have a significant effect whenever we substitute kinematic for actual distances.

Even if large-scale perturbations did not exist, two further effects would need to be accounted for in dealing with radiofrequency sources. They are more properly located in a probabilistic manner, because their velocity dispersion of 5 km s^{-1} (Lockman 1979) and the line-of-sight velocity gradients due solely to rotation (varying between 0 and 20 km s^{-1} kpc^{-1} in the inner Galaxy) together imply typical distance errors (± one standard deviation) of about a kpc. It is also the case that the center of mass of an HII region-molecular cloud complex usually resides within the molecular material, which may have a velocity a few km s^{-1} different from that of any recombination lines. The sign of the difference probably depends on which side of the cloud first encountered any galactic-scale shock, HII regions on the closer side being more likely to be expanding toward us, and the overall effect is a systematic one depending on our particular viewing angle.

Problems encountered in using kinematic distances are taken seriously by Lockman (1979), who still concludes that the densest HII regions in the inner Galaxy lie in a two-armed spiral pattern (although ring models cannot be excluded entirely). The salient feature of these sources is their avoidance of certain regions of the longitude-velocity plane, particularly near the maximum expected line-of-sight velocity from 30°-50° and 310°-330° (a characteristic which is certainly not shared by the HII or CO discussed in Section III and IV). This aspect of the observations is insensitive to the assumed underlying kinematics, because it is so gross an effect and cannot be replicated by imposing a perturbed velocity field on an axisymmetric surface-density distribution which is too broad in galactocentric radius. It is, however, well fit by confining the HII regions to the two-armed spiral of Burton (1971) which specifies the Scutum and Sagittarius features in the North and their counterparts in Carina and Crux in the South. Kinematics similar to those of the HII regions are also exhibited by the 1720-MHz OH clouds mapped by Turner (1983).

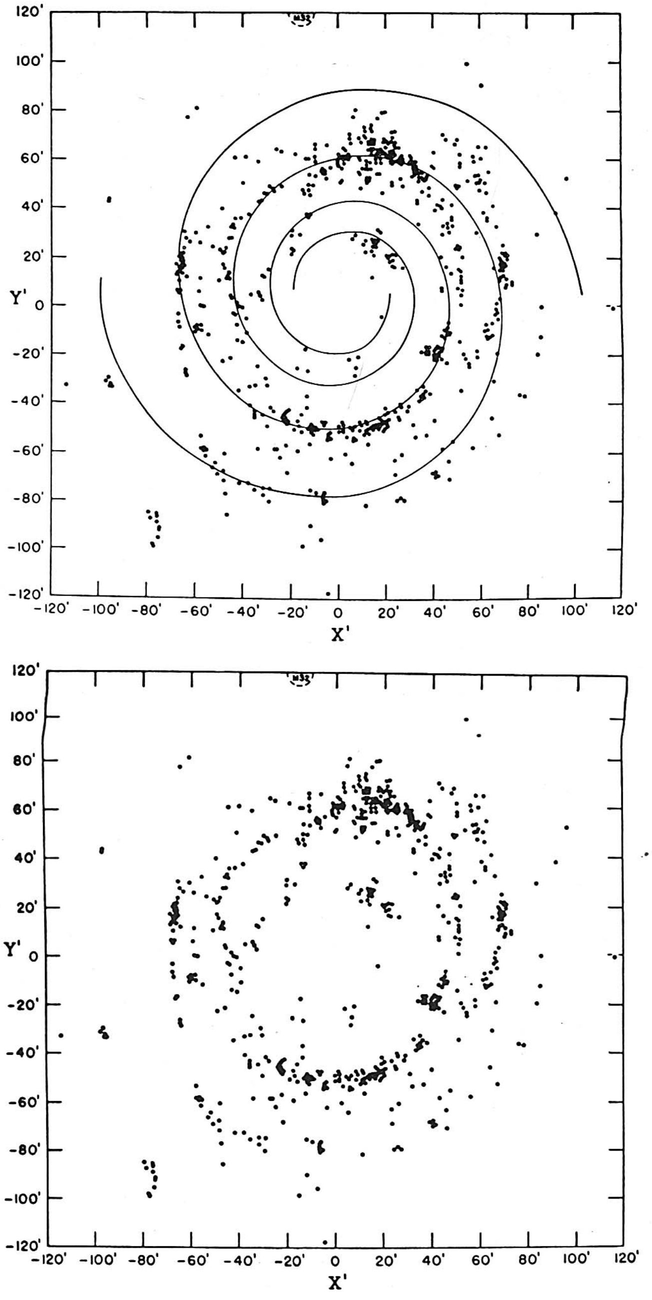

Figure 3. Deprojected positions of emission nebulae across the face of M31 (Figure 114 of Bok and Bok 1981), with and without a fitted logarithmic spiral. The Boks use this diagram to illustrate the difficulty of visual discrimination between spiral and ring distributions.

It is not actually necessary to exhibit an elegantly simple (and manifestly inconsistent) spiral as in Figure 2 in order to conclude that a definite pattern is present in the Galaxy. Much of the strongest evidence for such structure occurs in such a way that transformation from observational to Galaxy-centered spatial coordinates is difficult or impossible. One of the real embarrassments of Figure 2 is the proliferation of weaker sources near the Sun; most of these would not be detectable at large distances where the GG arms may appear to be well-defined. The usual excuse for such behaviour is the occurrence of a local arm or spur, and examples of the latter are often posited at larger distances to account for the presence of emission in regions which cannot be occupied by more major features. When too many of these minor features are present the overall grand design can become rather obscure.

How well should we have expected the HII regions to trace a grand design? Bok and Bok (1981) address this point, and their Figure 114 (due to Arp) is reproduced here as Figure 3. In those diagrams, the positions of 688 emission nebulae have been deprojected over the face of M31 and plotted with and without a fitted logarithmic spiral. The Boks stress that there is really no way to discern visually between ring structures and spiral arms, although the matter may clearly be forced by fitting one or the other distribution. This heuristic exercise must serve as a cautionary note for all the discussion here, as our perspective on the Milky Way is vastly inferior to that on Andromeda.

III. ATOMIC HYDROGEN

The most unambiguous and therefore strongest indicators of galactic spiral structure in the neutral gas species are perturbations of the circular velocity observed in the first and fourth longitude quadrants. These are shown for northern data (the HI survey of Westerhout 1976) in Figure 4, where the measured HI terminal velocity and the maximum projected line-of-sight velocity in the Burton-Gordon (1978) rotation curve are followed. The supposed tangent longitudes of the Scutum (30°) and Sagittarius (50°) features are accompanied by increases in velocity and the intervening or interarm region by a decrease of comparable magnitude; the perturbations occur over distances of order 800 pc across the line of sight. These fairly direct measures are usually (not always) taken as very strong constraints on possible spiral patterns, but our inability to observe similar effects in velocity away from the locus of sub-central points constitutes a serious obstacle in transforming the HI profile shapes into more "useful" information.

Another formidable obstacle is the longitude variation of integrated HI intensity, which exhibits only very minor deviations from the behaviour expected of a uniform axisymmetric gas distribution: in Figure 4 we show the results calculated for a constant density

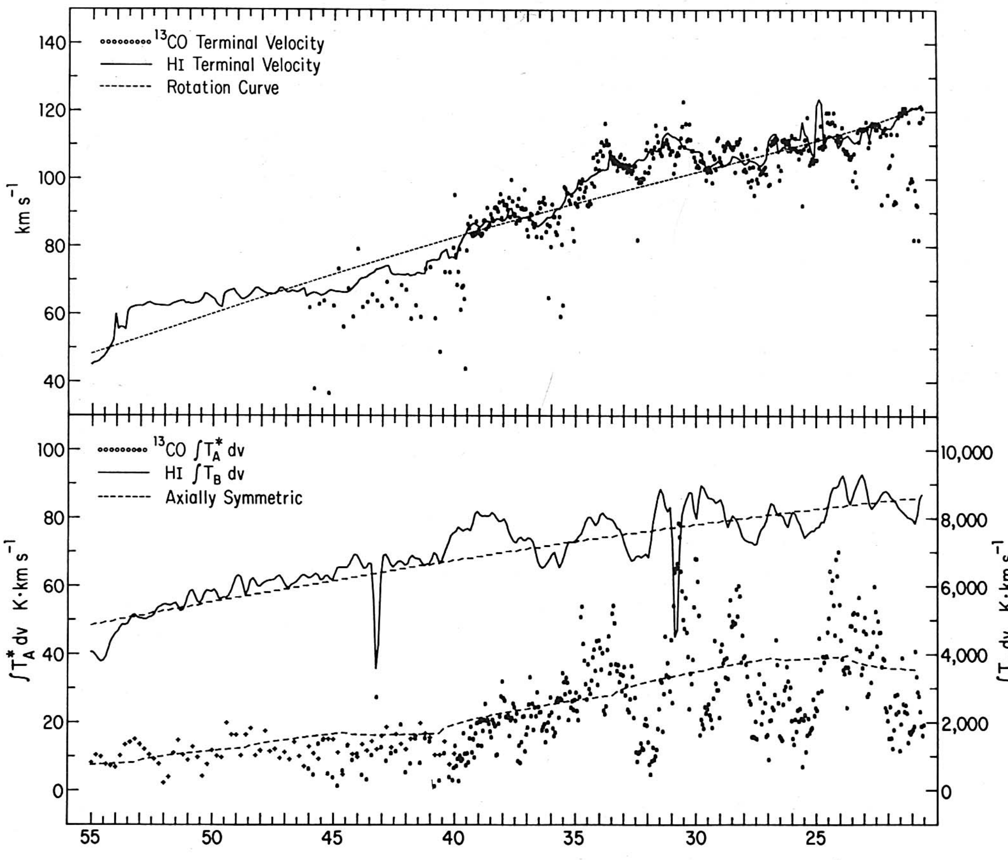

Figure 4. Upper panel: terminal velocities measured on HI (Westerhout 1976) and ^{13}CO (Liszt and Burton 1983) line profiles, and the maximum rotation velocity from Burton and Gordon's (1978) rotation curve. Lower panel: integrated intensities and the predictions of axisymmetric models. The HI model has constant density and temperature, the CO uses the usual intensity-abundance histogram derived from the data. The ^{13}CO data have been extended above 40° using scaled data of Burton and Gordon (1978).

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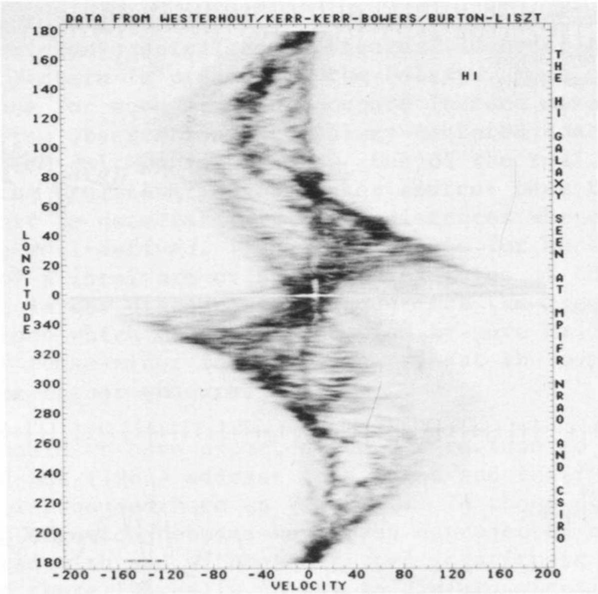

Figure 5. A grey-scale representation of HI profiles over the whole galactic equator with data of several observers, as indicated.

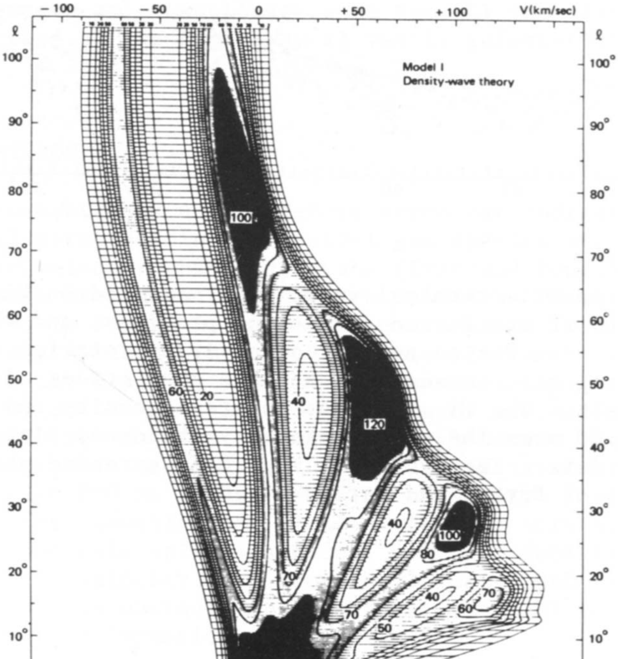

Figure 6. Model, schematic diagram of the main HI-intensity ridges in the first longitude quadrant from Burton (1974, 1971). The HI structures occur in CO as well.

0.38 H-nuclei cm^{-3} and spin temperature 125 K at R > 4 kpc. There is no observational peak corresponding to the tangent point of the Sagittarius Arm and very little for Scutum.

This is not to say that the HI is largely unstructured, for it certainly does display a high degree of ordering in ridges, loops, etc., as displayed in Figure 5, a presentation of the data over the whole galactic equator, and in Figure 6, where Burton's (1971, 1974) schematic model representation of the main intensity ridges is shown for the first quadrant. The model diagram was used to prove a fundamental point concerning HI intensity structures. They arise not from density enhancements at well-defined locations within an otherwise smooth distribution of gas in pure rotation, but from velocity perturbations such as we may observe more directly at the terminal velocity. The intensity enhancements do not represent added emission from extra material, but rather, emission that has been concentrated in certain velocity ranges at the expense of immediately adjacent portions of the spectrum. Portions of the spectrum corresponding to regions over which the line-of-sight velocity gradient is smaller--near the terminal velocity, and elsewhere if the gas motion is suitably perturbed--will have higher intensity than those in which it is large. Such an interpretation is of course entirely compatible with a nearly featureless run of integrated intensity with longitude. This circumstance was not self-evident when study of HI began, however, and its consequences for interpretation of CO (in which the same ridges appear) are still too often ignored.

We end this brief discussion of HI with a collage of some of the schematic spiral structures inferred to exist from HI observations, Figure 7 (the GG pattern and one other explained in Section V are included for comparison purposes). There is a remarkable variety of structure, especially considering that the observations are not in dispute at all, and surprisingly little consensus as to which aspects of the data should be weighted most strongly. The patterns shown represent only a few of those that might have been cited (see also Kerr 1970, Oort, Kerr, and Westerhout 1958, and Verschuur 1973), a veritable handbook of spiral anatomy occurring in the literature. There are few portions of either the longitude-velocity or inner galactic planes in which clear features have not been claimed to exist at some time.

IV. CARBON MONOXIDE

A. Integrated Intensities. While the kinematics of HI and CO are essentially identical, the run of their integrated intensities shows some important differences. The ^{13}CO data shown in Figure 4 (from Liszt and Burton 1983) have very strong peaks and troughs at several longitudes below 40°. Are these indicative of spiral arms? Only at 28°-31° can they be identified with intensity structures near the terminal velocity, while the rest occur in conjunction with emission concentrations occurring well below it (Figure 1 of Liszt and Burton

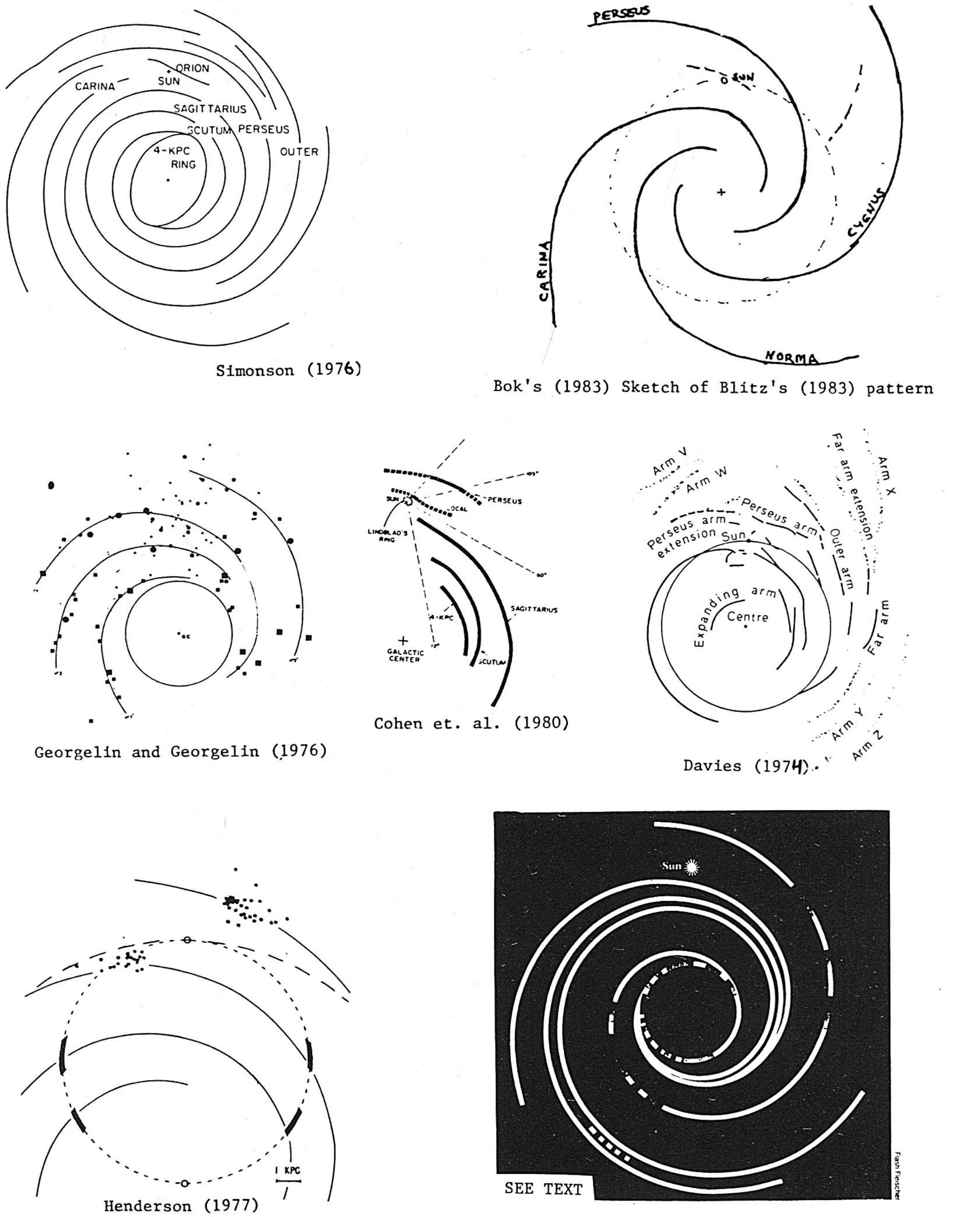

Figure 7. A few schematic spiral patterns inferred for the Milky Way. Except for the HII-region distribution (Georgelin and Georgelin 1976) and that in the lower right corner, all arise from consideration of essentially the same HI data.

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1983 but see also Figure 8 here). What the intermediate-velocity features actually represent is not clear, but they are not readily related to tangent points of spiral arms. Indeed, the entire Sagittarius feature is as little evident in CO as in the HI.

The integrated CO intensity differs in another respect from that of HI. While no feature considered as a single cloud can by itself cause substantial variations in the total atomic-gas quantity, the largest molecular clouds probably do make a definite appearance in CO. Taking the characteristic sizes of the peaks in Scutum, about 0.7°, as indicating cloud surface areas $< 10^4$ pc^2, and using the usual very uncertain CO-intensity→H-column-density conversion factors, the inferred masses associated with the observed intensity structures are 2-7 x 10^6 M_{Sun}. The mass spectrum of interstellar clouds is frequently inferred to extend to or even beyond these values, and the larger clouds should be manifested in the run of integrated intensity.

B. Kinematics. The kinematics exhibited by HI and CO are actually quite similar, both at the terminal velocity and below it. The first point is made by Burton and Gordon (1978) and by Liszt and Burton (1983), but the full extent of the congruent behaviour in HI and CO is revealed most clearly in the more fully sampled CO data of Cohen et al. (1980:CCDT). CCDT noted that the intensity loops and ridges used to define spiral structures in the HI are also visible in CO (although the near portion of the Sagittarius feature is very weak, even after summing over latitude), and we have reproduced their Figure 2 in slightly modified form to stress this fact (Figure 8). Actually, their rendition of the "4-kpc arm" feature is not exactly correct (see Bania 1980 and Cohen and Davies 1976), but the claimed kinematic similarities are unassailable.

CCDT advanced the argument, reminiscent of early interpretations of HI, that the CO ridges and loops represent density-based enhancements of the molecular intensity and, further, that their appearance in the CO implies that most molecular clouds are confined to a few spiral arms: because of its lower velocity dispersion, increased clumpiness and higher arm-interarm contrast, the molecular-cloud ensemble might yield CO spectra which are less susceptible to the kinematic perturbations plaguing HI. Reader, take note. If the observed structure can only arise in the HI as the result of kinematic effects, and if this same structure appears in the CO, then it must be the case that the same kinematic effects are present in the CO. Indeed, Liszt and Burton (1981) show that introduction of a perturbed velocity field creates a substantial degree of intensity structure in CO emission from the molecular-cloud ensemble and induces a sizable apparent arm-interarm contrast when none actually exists. The discussion of this matter in Liszt and Burton (1981) is too long to bear repetition here. Instead, we list a few of the problems which arise when the galactic spiral is inferred too naively (these remarks are not strictly limited to interpretation of CO).

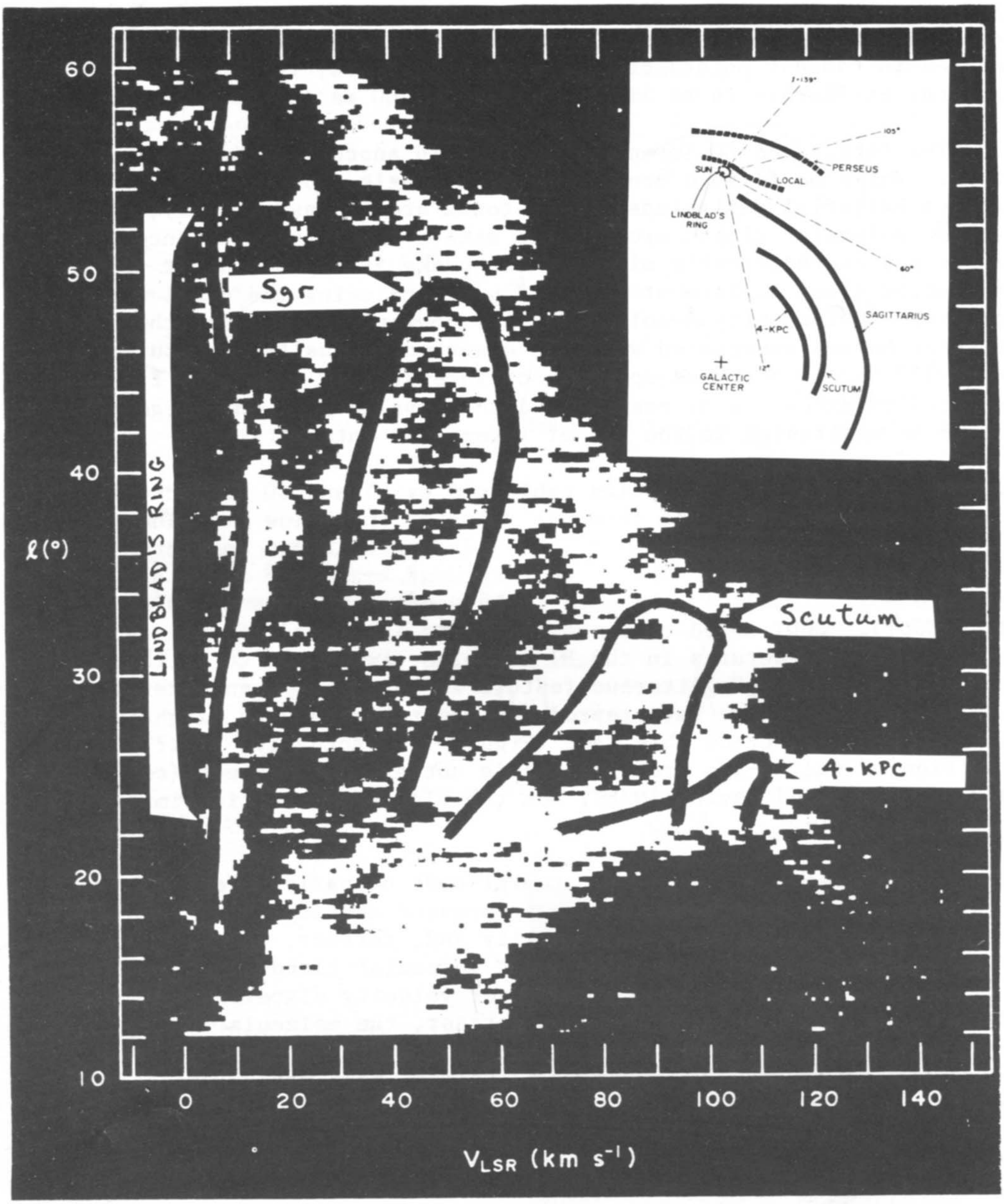

Figure 8. Grey-scale representation of ^{12}CO intensity, integrated over latitude, from Cohen et al. (1980). Major features are identified and sketched schematically in the insert.

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(1) Neglect of velocity perturbations may cause the inferred spiral pitch angle to be too large, necessitating the supposition of more arms than are actually present. With non-circular or perturbed motions, some part of the velocity separation between front and back portions of a spiral pattern arises from streaming, etc. Without it the same velocity difference can arise only by placing the two segments at different galactocentric radii, and the arms therefore unwind too rapidly with spiral phase angle.

(2) The positions of the arm tangents will be mis-estimated because of possible offsets in spiral phase between maximum line-of-sight density and associated velocity perturbations.

(3) The inferred arm-interarm contrast will be too large, leading to the creation of spurs and other complications to account for emission which cannot be straightforwardly associated with the major arm pattern.

Interpretation of the molecular data is and will remain controversial. One clear feature of the northern data in all surveys is the unmistakable presence of the terminal-velocity intensity ridge at all longitudes above about 20°, continuing past the supposed Scutum-arm tangent at longitudes 30°-50° and past the Sagittarius feature over the remainder of the first quadrant into Cygnus. Such behaviour is not exhibited by the HII regions, as detailed earlier. This situation may be taken by one observer as evidence that a substantial portion of the molecular-cloud emission arises outside spiral arms and by another as indicative of where to place various spurs and other spiral anatomy, with all molecular emission confined to a relatively few well-defined features in space. Some ordering of the molecular-cloud ensemble is clearly necessary, but the extent to which one engages in this process is very much a matter of personal preference (supported to varying degrees by the actual data).

There is one further caveat regarding demonstration of spiral patterns in the molecular material. Estimates of the number of galactic molecular clouds range from 3000 to more than 30 000 (see Liszt and Burton 1981). The subset of these clouds with "well-determined", larger (> a few kpc) distances numbers at most a few dozen,as it is limited to those which can be shown to be physically associated with HII regions whose kinematic distance ambiguity is resolved. The reader is cautioned to view with suspicion diagrams like Figure 2 in which only a handful of clouds are placed in perspective, and to question the placement of even those sources!

V. CO NORTH VS. SOUTH AND OTHER REFLECTIONS

CO data are now available for the fourth longitude quadrant, and Robinson et al. (1983) have performed a naive decomposition of the combined north-south data into kinematic loops and their associated

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kinematic spiral arms. Their results are as different from those of CCDT as are many of the HI patterns from each other, even though no new northern data are introduced. Still, the geometrical parameters of their four-armed pattern are claimed to be in only mild disagreement with those of the Georgelins or of Henderson (1977). The spiral pattern which occurs in the lower right-hand corner of Figure 7 appears in the May issue of Science 83 magazine attributed to McCutcheon and collaborators, but bears no resemblance to the geometry discussed by Robinson et al. (1983), which has McCutcheon as a co-author.

Molecular mapping is just now beginning over about half the sky, and perhaps it is too early to demand that a coherent picture of the molecular clouds emerge. But it is not too early to demand, in general, that the utmost care be taken in interpretation of the data. Essentially the same HI data have now been decomposed literally dozens of times into loops and arms, and HII regions placed in galactic perspective, without achieving anything like the degree of consensus necessary for progress toward the ultimate goal of such work. But some lessons have been learned from this process and they should be heeded even when they complicate and make less straightforward our interpretational efforts. Kinematic effects cannot be ignored in any phase of the analysis; more objective methods must be developed to gauge the reality, importance, and connectedness of kinematic loops and other features; more rigorous tests must be made of the validity of decomposition of the observations into major structures. Perhaps our expectations should be tempered. In the meantime, the question of galactic spiral structure remains, as over the past 30-year history of HI, open.

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DISCUSSION

W.L.H. Shuter: Are the wiggles along the tangent lines really due to a spiral field, or could they be related or connected in some way to the scalloping at the outer edge of the disk?

Liszt: In the context of models that have streaming motions, or perturbations of the circular motions associated with real spiral arms, those bulges in the (run of) terminal velocity (with longitude) are taken as direct evidence for the existence of spiral arms. The terminal velocity is, however, quite uniform on small scales; it varies on scales of 800 pc or so across the line of sight.

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H.C. van de Hulst: Since this is partly a historical meeting, I wish to point out that a number of your cautioning remarks can be found back almost literally in papers written around 1953.

Liszt: I am not saying my cautioning remarks are new. The unfortunate thing is that they are not always taken into account in CO papers written in 1983.

H. van Woerden: It is true that in some of the early papers attention was drawn to possible effects of non-circular motions. However, in these early papers such effects were generally considered to be minor. It was not until the late sixties (Burton 1966, Bull. astr. Inst. Netherl. 18, 247; Shane and Bieger-Smith 1966, Bull. astr. Inst. Netherl. 18, 263; Burton and Shane 1970, IAU Symp. 38, p. 397; Burton 1971, Astron. Astrophys. 10, 76; but see also Kerr 1962, Mon. Not. Roy. astr. Soc. 123, 327) that Burton and Shane demonstrated how seriously existing maps of the spiral structure of our Galaxy might have been distorted - or indeed counterfeited - by the effects of large-scale non-circular motions. (This comment was not made at the Symposium, but added later, for the sake of historical fairness - Editor.)

M.L. Kutner: You are using the lack of uniqueness of derived spiral patterns to discourage certain avenues of investigation. However, anyone who models anything complicated must learn to deal with non-uniqueness. Instead of looking for rules how to decompose the (l,V) plane, I suggest the procedure should be as follows: make a model of the Galaxy, including the kinematics, and then predict an (l,V) diagram.

Liszt: That is what I suggest in the end: do linear density waves, do nonlinear density waves, do two-armed spiral shocks, etc. - drive them, shear them, but at least start out with a model, and do not draw connecting lines in that (l,V) plane first.

A.A. Stark: My opinion is somewhat less pessimistic. We know there are external spiral galaxies in great variety. In our Galaxy we can identify arms and interarm regions - it may just be impossible to connect them up.

Liszt: I wish that were true. When it comes to a vote, I probably agree with your arms and interarms - but what do you do if I draw somebody else's pattern in this plane?

Stark: But surely, in the (l,V) diagram you can distinguish arm and interarm regions, and study objects in these regions, and forget about a global pattern.

Liszt: But what you call an arm, may not be somebody else's arm. And the philosophy in this game is: If you don't see what I see, you're blind. Of course, I agree that you have a valid way of defining arms.

And I agree with your interarm regions, they are ... between arms ... if such exist. But various observers have not come to the same conclusions - it was not as obvious to them what an interarm region was as it was to you, looking at the data.

Stark: There is one arm that everyone agrees on, and that is the 4-kpc arm, or 3-kpc arm, depending on what .... (Laughter).

Liszt: Right, there is one arm that everybody agrees on, and there may be spiral arms, hands, legs and feet. ----- In our Galaxy, the 4-kpc arm is one of the most enigmatic features, and it is associated with inner-Galaxy phenomena which probably do not propagate into the disk in their full glory.

F.J. Kerr: You said that we do not have guidelines. In fact, one guideline has been used by many people, namely they look for a very regular spiral pattern. However, this guideline must be wrong, as no other galaxies are so regular.

Liszt: We can learn from Dr. Elmegreen's review of external galaxies what it means to have a grand design: it may be grand, but it is not always as pretty as we like.

(The following remarks were made in the Discussion after the next paper, by B.G. Elmegreen, but their contents fit best here - Editor.)

F.J. Kerr to Elmegreen: You spoke of Gould's Belt-type complexes. A striking thing about Gould's Belt is its inclination to the galactic plane. We do not see such features in other galaxies.

B.G. Elmegreen: The shingles described by Schmidt-Kaler and House have a similar inclination. This phenomenon is not understood.

Kerr: But there is nothing similar in the CO known sofar.

Elmegreen: The classical Gould Belt is rather thin, with a large velocity dispersion. Its mass is too low for self-gravitation. It is unclear how it is held together, for it is much older than would follow from its width and velocity dispersion. The thinness and inclination may partly be a result of obscuration by dust.

R.S. Cohen: Liszt is not correct when he cites our 1980 paper as an example of yet another grand-design spiral model. The lines drawn in that paper are definitely not intended to be a grand-design model, they were drawn long ago by Burton on the basis of 21-cm data and were used in our paper simply to illustrate the clarity with which CO outlines previously identified HI features. One of the features in our diagram is the Cygnus Rift, a nearby naked-eye object. The inner Galaxy is much more complex, and I completely agree with Liszt that it is a mistake to fit logarithmic spirals naively. Nonetheless, I do think we see arm regions and interarm regions: there are regions rich in CO and others poor in CO. The confusion is how to connect things into a grand design, and I do not think we know how to do that yet.

B.G. Elmegreen: Part of the confusion about the Sagittarius Arm is a result of the clumping of CO clouds. Between the M16-M17 complex and the next clump in the Sgr Arm there is a huge gap. This is just due to the beady structure of spiral arms, which we can now study in our Galaxy, because we have distances to these clumps.

Liszt: Your spiral arcs are lines of almost constant velocity in the (l,V) plane, they are loops and ridges in the (l,V) plane placed in perspective in the galactic plane through an assumed rotation curve. And in fact I don't think many of those distances are really defensible - in many instances you have HII regions that are 1°.5 or 2° away, which you associate with a CO cloud to put it at a certain distance.

W.H.M. McCutcheon: One thing evident in the data of our Southern CO survey is the very clumpy emission along the run of terminal velocities. The holes are large and cannot be the result of non-circular velocities or streaming motions. The CO (l,V) diagram supports a gas distribution in large-scale features which undoubtedly consist of spurs and bifurcations, as well as segments of spirals. We do not want to claim a neat spiral pattern, but rather emphasize the large-scale, quasi-continuous features. An alternative view, expressed in a paper of which Liszt was co-author and suggesting that the emission can be accounted for by a random distribution of clouds, is not supported by our data.

At conference dinner, clockwise: Lynden-Bell, Burton, Jog, Mirabel, and Liszt looking diffidently at Ostriker LZ

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