Report on the ESO Workshop

Spiral Structure in the Milky Way: Confronting Observations and Theory

held at Bahía Inglesa, Copiapó, Chile, 8–11 November 2010

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The main objectives of the workshop were to review current observational evidence for spiral arms in our Galaxy and confront them with models of spiral structure in order to arrive at a consistent picture. Of primary importance was to understand just what additional information is required to resolve outstanding issues related to the spiral structure in the Milky Way, especially as new survey instruments (e.g., ALMA, VISTA and VST) are coming online and major space missions like GAIA will be launched in the near future.

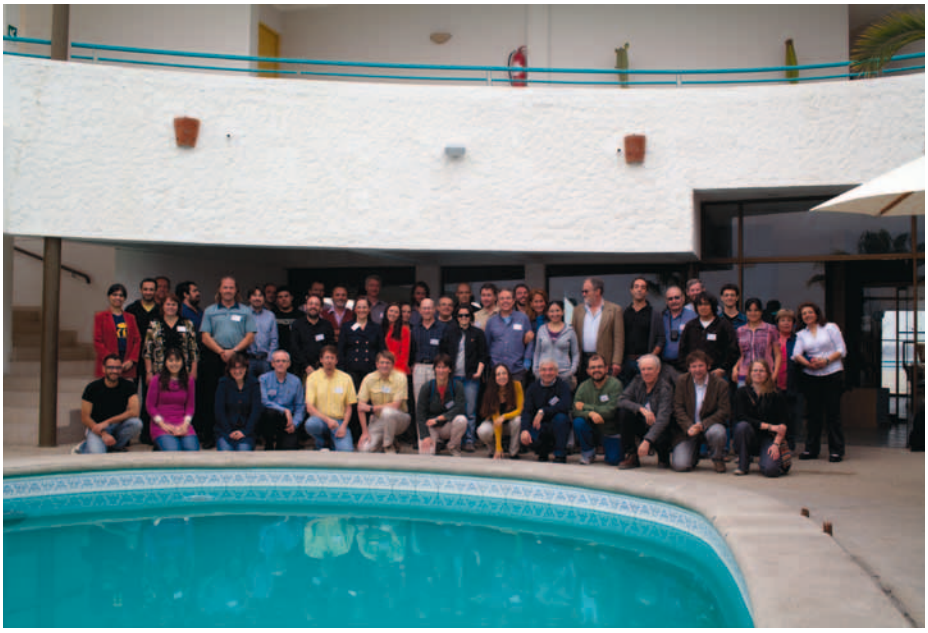

Figure 1. The participants by the swimming pool at the conference venue, the Hotel Rocas de Bahía in Bahía Inglesa.

More than 50 years ago, the spiral arms of the Milky Way were identified in the distribution of OB-stars, H II-regions and neutral hydrogen. An overview of the early results was presented in the proceedings of the IAU Symposium 38 held in 1969, in Basel, Switzerland. Our knowledge of the evidence for spiral arms in the Milky Way and the kinematics in the Solar Neighbourhood has increased significantly over the last few decades. Despite this, there is still no consensus on the basic parameters of the spiral structure in our Galaxy, such as the number of major spiral arms and their location, its pattern speed(s) and amplitude, and its relation to the central bar. Major new and future observational facilities (such as ALMA, GAIA, LSST, VISTA, VST and APOGEE) will provide a wealth of data on the spatial and kinematic distributions of the material in the Galaxy. Thus, it seemed appropriate to perform a census of our current data, confront them with theory and models of spiral structure, and thereby map the path towards a consolidated view of the spiral pattern in the Milky Way. The workshop was held at the small, beautiful seaside resort of Bahía Inglesa in Central Chile over a period of three and a half days. It was a pleasure to see many students among the 55 participants (see Figure 1), the number being limited by the off-season availability of accommodation.

Observations

Recent observational data suggesting a spiral structure in the Milky Way were reviewed during the first two days of the workshop. H I/CO maps of the Galaxy have much improved both in sensitivity and resolution (presentation by T. Dame; see the workshop web page[1] for more details). This has led to a better outline of the spiral arms, especially on the far side of the Galaxy, even though uncertainties in the rotation curve and the distance ambiguity still present issues. The identification of a symmetric counterpart to the 3-kiloparsec arms was made possible by the high resolution radio data. Accurate parallaxes to numerous masers have been determined using very long baseline interferometry (VLBI) techniques (talks by M. Reid, M. Sato and M. Honma). Since masers are located in Giant Molecular Clouds (GMCs), this has led to much better estimates of the shape of the arms. Measurements of parallaxes and the proper motion of the central source in the Galaxy provide a new independent estimate of the rotational velocity of the Sun. H I self-absorption observed in the second Galactic quadrant (GQ) suggests a shock in the gas associated with the Perseus arm. New all-sky radio maps in the range 45–408 MHz show four tangential points associated with synchrotron radiation in spiral arms, consistent with a four-armed pattern (A. Guzmán).

GMCs and the massive stars in the southern Milky Way were identified by combining the new Columbia survey and IRAS data (P. Garcia-Fuentes). They follow the spiral structure with some scatter and include several massive GMCs in the Norma arm. New spectrophotometric distances have significantly improved the mapping of young stellar clusters in the Galaxy (A. Moitinho & A. Daminelli). There seems to be a lack of giant H II regions on the far side of the Milky Way. The Perseus arm is well defined by CO clouds, but is deficient in clusters. Using near-infrared (NIR) surveys such as GLIMPSE, a global view of the most massive, young stellar clusters was assembled (M. Messineo). Only clusters younger than 30 Myr display spiral structure in the Solar Neighbourhood (A. Lokin & M. Popova). Their ages and relative locations suggest a co-rotation radius just outside the Sun. A survey of early-type stars in the anti-centre direction using Strömgren photometry, which provides accurate distances to individual stars, indicates a density enhancement associated with the Perseus arm (M. Monguío). The IPHAS survey questions the existence of a sharp truncation of the stellar disc (S. Sale).

The general spiral structure displayed by young objects and gas agrees well with, and is best fitted by, a four-armed pattern (D. Russeil). Kinematic distance estimates are not always reliable due to possible systematic perturbations by a density wave. NIR star counts using 2MASS and GLIMPSE can give structural information when the underlying stellar population has features in its magnitude distribution like the red clump (R. Benjamin & P. Polido). In integrated longitude–magnitude diagrams, structures in the bar and bulge can be seen as tangential points of spiral arms and the truncation of the disc. The distribution of CS emission sources in the Galactic Plane shows a squared feature which resembles the orbital shape near the 4:1 resonance (J. Lépine). Spiral and bar perturbations in external galaxies and possible implications for the Galaxy were also discussed (M. Arnaboldi & M. Dumke).

Figure 2. The conference poster, showing the major features of the Milky Way spiral structure.

Theory

The third day of the workshop was dedicated to theoretical models and their comparison with observational data. Magnetohydrodynamic simulations in a realistic Galactic potential show that the response to a two-armed spiral perturbation in the stars can yield additional, slightly tighter, arms of compressed gas between the stellar arms (M. A. Martos & G. Gómez). The Galactic bar may drive the spiral pattern and induce additional gaseous arms, which will look like a four-armed pattern (O. Gerhard). New analytic models of the Milky Way were presented and used to analyse the importance of ordered and chaotic stellar orbits (B. Pichardo & S. Villegas). The velocity ellipsoid can be used to test different potential models with spirals and bars (D. Chakrabarty & B. Famaey). Although it is non-trivial to define a best fit to such distributions, they indicate that the spiral has a significantly lower pattern speed than that of the Galactic bar. Radial mixing can be estimated from pencil beam surveys and used to place constraints on possible spiral modes in the Galaxy and their lifetime (I. Minchev). Unstable spiral modes can be present in stellar discs depending on the radial distribution functions of rotational velocity, dispersion and surface density (V. Korchagin). The number of arms and the pattern speed of the growing modes depend on these functions and suggest a four-armed pattern for a standard model of the Milky Way.

Future surveys

Finally, the last half-day was dedicated to future surveys. Several new surveys are being prepared and will improve our knowledge of the stellar disc by orders of magnitude. VISTA surveys in the NIR will allow a much better view towards the centre of the Galaxy while GAIA will assemble both spatial and kinematic data for more than a billion stars (V. Ivanov, J. Alonso-Garcia & J. de Bruijne). Surveys like APOGEE using SDSS-II data are improving the kinematic data significantly (S. Majewski).

Discussions

During the last two days of the workshop, more than three hours were devoted to intense discussions of observations and models. The two main topics were the topology of the arms and the possible angular speed of the pattern. There was wide agreement that gas and young objects show a four-armed structure with pitch angles in the range of 12–14 degrees. The major issue is whether the older stellar component has only a two-armed structure (Perseus and Scutum–Centaurus) or also four arms. In the former case, the two minor gas arms (Sagittarius and Norma) would either be generated by secondary compressions or driven by the bar. It would be possible to distinguish these options by more accurate mapping of the arms (e.g., by VLBI parallaxes of masers) and detailed analysis of the stellar density–velocity field in a region of a few kiloparsecs around the Sun. Whereas new surveys (e.g., VISTA and GAIA) will provide accurate mapping of the stellar component, radial velocities may still be an issue.

The current data are consistent with the observed spiral pattern being associated with a density wave. The life span of such waves in the Galaxy is not easy to evaluate, as only very indirect means can be used, such as radial mixing and changes of velocity dispersion with the mean age of the stellar populations. Most estimates of the pattern speed of the spiral arms show values significantly lower than that of the bar, suggesting that the disc of our Galaxy has at least two components with different pattern speeds. While star formation and shocks in the gas of the Perseus arm second GQ indicate co-rotation for the spiral to be outside this radius, the kinematics of local young clusters place it much closer to the Solar radius.

Acknowledgements

We express our deep gratitude to Paulina Jirón, Hernan Fernandez, Mariía Eugenia Gómez and the entire Local Organising Committee for a very successful meeting.

Links

[1] Conference web page: http://www.eso.org/sci/meetings/MW2010/index.html