Tumbling, Twisting and Winding Galaxies: Pattern Speeds Along the Hubble Sequence

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FOREWORD

"Tumbling, Twisting and Winding Galaxies: Pattern Speeds Along the Hubble Sequence" took place in Padova from August 25 to 28, 2008. For a wide range of non-axisymmetric phenomena in galaxies, the pattern speed plays an important role in their long-term evolution and dynamics. During four hectic days, the participants delved into pattern speeds, covering topics as diverse as bars, spirals, lopsidedness, and the tumbling of triaxial dark matter halos.

Bars are one of the most common perturbations in disk galaxies, as shown by *Irina Marinova*. Their ability to re-arrange the mass distribution attracted a good deal of attention. It was discussed by *Judith Bakos, Dimitri Gadotti, Jairo Méndez-Abreu, Olga Sil'chenko,* and *Michael Williams*. According to *Michael Merrifield* and *Enrico Maria Corsini*, it now appears that bars rotate rapidly, ending near their corotation radii. Methods for pattern speed measurement continue to be tested and refined using simulations as done by *Joris Gerssen* and *Isabel Pérez*. This gives us confidence in using them. But new methods are also being developed and two of these were showcased at the workshop by *Ron Buta* and *John Beckman*, respectively. Beckman suggested that the Tremaine-Weinberg method applied to Hα returns reasonable values for bar pattern speeds; considering how much easier gas velocity fields are compared with stellar velocity fields, this result warrants further investigation. Buta presented the density-potential phase shift method; in a few cases application of this method finds bars ending well inside their corotation radii (i.e., the bars are "slow"), especially in late-type disks. Independent verification of such slow bars, which is vital for such a new method, would prove very exciting since none are known in high surface-brightness galaxies. Simulations now suggest new ways for bars to remain fast, in the sense described above. *Françoise Combes* suggested that bars may avoid slowing down by continuously dissolving and re-forming. Alternatively, *Isaac Shlosman* discussed how bars may grow to a large fraction of their host disks, allowing them to remain in the fast regime.

Perhaps no problem in galaxy dynamics has been unresolved for as long as is the nature of spiral structure. While density wave theory has become the basis for understanding spiral structure, whether the waves are stationary or dynamically evolving remains unknown. Both views were presented at the workshop. *Lia Athanassoula* and *Merce Rómero-Gomez* argued that spirals can result from flows along bar's invariant manifolds at the Lagrange points, and *Panos Patsis* delved further into the role of both regular and chaotic orbits in supporting spiral structure. Meanwhile, *Clare Dobbs* argued for spirals with radially varying pattern speeds. These predictions seem quite distinct from each other. Observational estimates of spiral pattern speeds, using either young star clusters or CO gas were presented by *Preben Grosbøl* and *Sharon Meidt*, respectively. The CO study is a full kinematic measurement using a recent extension of the Tremaine-Weinberg method. In particular, Meidt finds evidence that the pattern speed is not constant with radius, hinting at non-stationary spirals. This example illustrates that observers may finally be in a position to provide the data for settling the old debate between proponents of stationary and transient spirals. More such studies are needed, to build the statistical samples necessary to solve this long-standing riddle.

We know almost nothing about the pattern speeds of lopsided ($m = 1$) perturbations. As stressed by *Chanda Jog* even a few measurements of lopsided pattern speeds can substantially advance our understanding of these perturbations. However, it is also unclear what is needed to measure them. The problem lies in the fact that we do not know for certain how they oscillate. They may rotate uniformly like bars, as discussed by *Sven De Rijcke* or involve radial oscillations too. The measurement of pattern speeds in triaxial halos directly tests predictions of low rotation rates from cold dark matter simulations. But observational measurements have not progressed much since Bureau and collaborators proposed a tumbling halo to explain the spirals in the low density outer regions of NGC 2915. *Dalia Chakrabarty* finds that one consequence of a tumbling halo may be the excitation of a warp. Further study of warps excited by this mechanism, to distinguish from other warp-generating mechanisms, may help probe some of the most difficult to measure pattern speeds in nature.

As interest in the feeding of supermassive black holes and nuclear star clusters grows, so will our need to better understand the nuclear pattern speeds that may drive some of this evolution on these scales. *Lei Hao* reviewed the connection between bars and nuclear activity. *Nemesio Rodríguez-Fernández* reported finding no compelling evidence for a distinct nuclear pattern speed in the Milky Way. Theory however predicts that nested bars have different pattern speeds *(Witold Maciejewski)*, and the random relative orientation of nuclear and primary bars provides indirect support decoupling *(Peter Erwin)*. As with the Milky Way, the stellar kinematic signature of the nuclear bars is not always obvious, both observationally *(Alexei Moiseev)* and in simulations *(Juntai Shen)*. However, the CO data presented by *Viviana Casasola* supports the idea that the signature of independently rotating bars may be easier to detect in gas than in stars.

For our own Milky Way galaxy, measurements of the bar pattern speed continue to give conflicting results. Modeling of perturbed stellar velocities in the solar neighborhood *(Ivan Minchev)* gives higher values than gas-dynamical models at the galactic center *(Nemesio Rodríguez-Fernández)*. As the bar pattern speed has consequences for the kinematics of stars in the solar neighborhood, it is vital that this number is pinned down better. *Antonella Vallenari* pointed out that perhaps this will be possible with the huge database that ESA's Gaia will provide. Possibly, Gaia will also provide enough information to determine the pattern speed of the Milky Way's spiral structure, which is still incompletely understood as shown by *Peter Englmaier*. In his review of the Milky Way's bar and spiral pattern speeds, *Ortwin Gerhard* stressed that although their values are not known with great accuracy, they are clearly decoupled, i.e. the spirals rotate with a different (slower) pattern speed than the bar.

After the theorists had presented their predictions and the observers their measurements, what emerged from the workshop was a sense of the broad range of topics that can be advanced by a better knowledge of pattern speeds as remarked by *Victor Debattista* in his conference summary. We hope that this workshop will serve to further stimulate efforts at their measurement and comparison with theory.

We take this occasion to thank the Department of Astronomy of the University of Padova and the Astronomical Observatory of Padova for sponsoring this workshop. The location, in the castle behind the thick walls of the Observatory complex, made for a wonderful experience by all the participants, many of whom only reluctantly left this prison after four days. Our scientific organizing committee helped us define a programme that was broad and exciting and to them we also owe our thanks. We are especially indebted to our local organizing committee, who ensured that the workshop ran smoothly, and who distilled the best of Padova for the enjoyment of the participants.

Enrico Maria Corsini
Victor P. Debattista

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