Notice of the Final Oral Examination
for the Degree of Doctor of Philosophy

of

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MSc (University of Victoria, 2016)
BSc (University of Victoria, 2014)

“Morphological and Kinematic Indicators of Structural Transformation in Galaxies”

Department of Physics and Astronomy

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10:30 A.M.
Remote Defence

Supervisory Committee:
Dr. Luc Simard, Department of Physics and Astronomy, University of Victoria (Co-Supervisor)
Dr. Sara Ellison, Department of Physics and Astronomy, UVic (Co-Supervisor)
Dr. Katherine Elvira, Department of Chemistry, UVic (Outside Member)

External Examiner:
Dr. Julia Comerford, Department of Astrophysical and Planetary Sciences,
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Chair of Oral Examination:
Dr. Stephen Lindsay, Department of Psychology, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies
Abstract

The observed properties of galaxies are intricately connected to their respective evolutionary histories. Establishing these connections - tying the morphologies, dynamics, and other properties of galaxies to the dominant events and processes from which they originate - is the central challenge in creating a self-consistent framework for how galaxies form and evolve. Overcoming this challenge requires that two criteria be satisfied: (1) accurate characterization of the physical states of galaxies; and (2) creation of models that connect the observed features of galaxies to their evolutionary histories. This thesis chiefly concerns the identification and characterization of morphological and kinematic indicators for structural transformation in galaxies and their connections to galaxy mergers - including merger status (merger or non-merger) and merger stage.

Accurate measurement of the morphological structures of galaxies is a cornerstone for making connections to their evolutionary pathways. However, without significant overlap between the observational footprints of deep and shallow galaxy imaging surveys, the extent to which structural measurements for large galaxy samples are robust to image quality (e.g. depth, spatial resolution) cannot be established. Deep images from the Sloan Digital Sky Survey (SDSS) Stripe 82 co-adds provide a unique solution to this problem - offering 1:6 - 1:8 magnitudes improvement in depth with respect to SDSS Legacy images. Having similar spatial resolution to Legacy, the co-adds make it possible to examine the sensitivity of parametric morphologies to depth alone. Using the GIM2D surface-brightness decomposition software, I provide public morphology catalogs for 16,908 galaxies in the Stripe 82 ugriz co-adds. The methods and selection are completely consistent with those of previous analyses in the shallow images. Measurements in the deep and shallow images are rigorously compared. No systematics in total magnitudes and sizes are found except for faint galaxies in the u-band and the brightest galaxies in each band. However, characterization of bulge-to-total fractions is significantly improved in the deep images. Furthermore, statistics used
to determine whether single-Sérsic or two-component (e.g. bulge+disc) models are required become more bimodal in the deep images. Lastly, I show that morphological asymmetries (commonly linked to mergers) are enhanced in the deep images and that the enhancement is positively correlated with the asymmetries measured in Legacy images.

Recently, machine learning has become a popular tool to quantify galaxy morphologies and identify mergers - exploiting the often disturbed and asymmetric morphological features present in merging galaxies. However, this technique relies on using an appropriate set of training data to be successful. By combining hydrodynamical simulations, synthetic observations and convolutional neural networks (CNNs), I quantitatively assess how realistic simulated galaxy images must be in order to reliably classify mergers. Specifically, I compare the performance of CNNs trained with two types of galaxy images, stellar maps and dust-inclusive radiatively transferred images, each with three levels of observational realism: (1) no observational effects (idealized images), (2) realistic sky and point spread function (semi-realistic images), (3) insertion into a real sky image (fully realistic images). I show that networks trained on either idealized or semi-real images have poor performance when applied to survey-realistic images. In contrast, networks trained on fully realistic images achieve 87.1% classification performance. Importantly, the level of realism in the training images is much more important than whether the images included radiative transfer, or simply used the stellar maps (87.1% compared to 79.6% accuracy, respectively). Therefore, one can avoid the large computational and storage cost of running radiative transfer with a relatively modest compromise in classification performance. Making photometry-based networks insensitive to colour incurs a very mild penalty to performance with survey-realistic data (86.0% with $r$-only compared to 87.1% with $gri$). This result demonstrates that while colour can be exploited by colour-sensitive networks, it is not necessary to achieve high accuracy and so can be avoided if desired. I provide the public release of the statistical observational realism suite, REALSIM, as a companion to this work.
Galaxy kinematics derived from observational integral field spectroscopy (IFS) may offer an orthogonal and highly complimentary basis to photometry for accurately identifying and characterizing observed galaxy mergers. As with morphology, mergers can trigger kinematic disturbances in galaxies resulting in irregular and asymmetric kinematic structure. However, these kinematic disturbances are not always reflected in the morphologies. The current and future state-of-the-art IFS instruments which provide spatially-resolved kinematics for many thousands of galaxies make kinematic merger studies statistically viable. Anticipating the demand for realistic synthetic IFS and kinematic data for calibrating merger classification models with simulations, I present REALSIM -IFS: a novel tool that emulates the instrumental response of current and future fibre-based IFS instruments. Components of REALSIM -IFS are tested on real IFS data from the Mapping Nearby Galaxies at Apache Point Observatory (MaNGA) survey to demonstrate the high precision that is achieved by REALSIM -IFS. In a further demonstration with REALSIM -IFS, I generate realistic synthetic MaNGA kinematic observations for a sample of galaxies from the IllustrisTNG cosmological hydrodynamical simulations. The survey-realistic kinematic maps for post-merger galaxies are compared with non-merging galaxies to illustrate the potential role of kinematics in enabling more accurate identification and characterization of galaxy mergers (either independently or in tandem with photometry).