Studying the orbits and interactions of satellite galaxies in the next generation of surveys and simulations

PhD Project proposal

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Contents

1 Summary

Understanding the formation and evolution of galaxies through cosmic time is a fundamental problem in astronomy. Much work has been done on the subject but the complex nature of galaxies, which interact with their environment and undergo many processes, makes it hard to be well understood. The merging process, for instance, changes the properties of the galaxy, from its colour to its composition.

From observational and theoretical studies, it has been shown that the environment plays a crucial role in galaxy formation and evolution. This is the focus of this PhD project. Using state-of-the-art simulations along with observations, I will study how galaxies interact with their ever-changing environment, particularly when they are passing close to, or merging with, a larger galaxy.

2 Background

From observations of galaxies, it is found that they can be classified into two main categories. One is called Early-Type (ellipticals), which have the properties of being spheroidal and contain old stars, hence they tend to be much redder in color. The second type is called Late-Type (spirals) which typically have the properties of being disks and have young stellar populations (Wheeler et al., 2014). Spirals tend to be bluer in color than ellipticals because they are forming more stars (high star formation rate) (Binney & Tremaine, 2011).

A well understood process that transforms spirals into ellipticals is by spirals merging together following a hierarchical model, where small galaxies merge to make larger galaxies (Searle & Zinn, 1978). However, what is not understood is why spirals are bluer with lots of star formation while ellipticals formed by merged spirals are redder with little star formation, with the change happening quite rapidly in cosmic time (Baldry et al., 2004). The "rapid" change in color must means that the merged galaxy's star formation rate (SFR) has declined, resulting in the red color of older stars population.

In order to have high SFR, galaxies need to have cold dense gas, which undergoes gravitational collapse to form stars. To "quench" star formation, a process is needed to heat up or remove this cold gas reservoir from the galaxy so new bluer stars do not form.

From observations, it was found that quenching is most important within groups or clusters of galaxies. Hence it must be due to the environment that the galaxies live in that causes quenching, due to the high density of galaxies and hotgas (Davies et al., 2016). Some of the processes that results from the environmental interaction are:

- Strangulation - This process happens when the galaxy falls into the cluster environment, causing the hot gas contained within the galaxy to escape. This results in the galaxy burning through its limited cold gas reservoir as hot gas is unavailable to be cooled down to replenish the supply, hence "strangled" (Larson et al., 1980).

- In ram-pressure stripping - As the galaxy moves through the hot, X-ray emitting gas between the galaxies in the cluster, it experience the gas much like a wind. Ram pressure stripping occurs when this wind is strong enough to remove its gravitationally bound cold gas (Abadi et al., 1999).

These processes play some role in the quenching of smaller satellite galaxies, though their importance remains uncertain (Wetzel et al., 2013).

In a given time, we can observe that there are a certain amount of satellite galaxies that have been quenched (stopped forming stars) in the universe. However, when we try to reproduce this using simulations, it is often found that there are too many satellites that have been excessively quenched due to them being gas poor, which demonstrates that the quenching process is still not fully understood (Brown et al., 2017). The aim of this project is to quantify the importance of the quenching processes.

3 Research Project

3.1 Proposed project

3.1.1 Aims

The main aim for this project is to study the quenching process of star formation in satellite galaxies in simulations. This will be achieved by:

- Tracking halos when they disappear and are no longer found in the simulations (what is known as halo "ghosting")
- Constructing accurate orbits for subhalos - the most accurate achieved so far.
- Implementing what is learnt from the orbit analysis into Semi-Analytical Models to provide a more accurate model of how the environment affects the quenching process.

3.1.2 Computational tools

We propose to do this by looking at the orbits of satellites in simulations and investigating the possible reasons galaxy quenching happens. By studying these orbits, we hope to find out how gas is stripped from the satellites. We can also determine when the cold gas becomes hot gas and the timescales on which this happens . In addition we can identify hot gas that is stripped off and the rate at which this occurs.

To study this, we simulate dark matter particles using what is known as "N-body simulation". This tracks the growth of cosmic structure in dark matter. Dark matter particles are used since they only interact gravitationally, so are simple and computationally inexpensive to simulate. In general, clumps of dark matter particles, known as halos host galaxies, are used to track galaxies position since dark matter makes up $>80\%$ of matter in the universe. For this project, we use a simulations suite known as Synthetic UniveRses For Surveys (SURFS) (Elahi et al., In prep). These simulations are constructed assuming the standard cosmological paradigm known as Λ Cold Dark

Matter (ΛCDM) with parameters according to the Planck Satellite (Collaboration, 2016), using the simulation code GADGET-2 (Springel et al., 2005). These simulations will probe galaxies across a wide range of scales and time, with box sizes ranging from 40 Mpc/h to 20 Gpc/h with 512^3 to 8192^2 dark matter particles.

Once the simulations have been run, halos need to be identified within the simulation using a halo finder. The halo finder I will use is called VELOCIraptor (Elahi et al., 2011). It does this by linking together particles that are within a distance of each other, known as a linking length. This is also done for velocity space, where particles with about the same velocity are linked. If both these conditions are true, then the particles are linked and form a halo. Since halos have a large extent, they can contain other clumps of dark matter particles. These separate clumps are called subhalos when they are inside another halo.

Since it requires a lot of disk space to save the simulation every time something changes, "snapshots" are saved at certain time-steps in the simulations. In order to trace the evolution of a halo, the particles in the halo need to be linked across these snapshots; this is the job of a halo tree builder. The halo tree builder which I use is known as Treefrog (Avila et al., 2014). It tracks particles and evaluates which halo the particles mostly go into, which can then be linked to the donor halo in the previous snapshots. It also links together halos which have merged. Tracing the merger history – the merging of the halos to form a single halo in the final snapshot – is known as a dark matter halo merger tree.

3.1.3 Halo ghosting

There is a limit on how well VELOCIraptor can track halos, especially as they enter into high density region such as a larger host halo. This is because they can no longer be picked out from the background density thus they can no longer be identified by the halo finder. But by using the proposed technique in (Wetzel et al., 2014), these "lost" halos can be identified using a simple method. This involves using the lost halo's most bound dark matter particles and determining the particles that are gravitationally bound to them once the halo has been lost. The method is known as "ghosting" and it enables the halo to be tracked until it becomes completely gravitationally unbound. This step is crucial to the project because it means that the satellite galaxy can be tracked to when the particles have become gravitationally unbound and also determine its properties such as mass loss rate, which is key to what we are studying.

Once halo ghosting has been proven to work, the next stage would be to implement this as part of the VELOCIraptor code. It will be added as an extra step once the halo finder and the halo linker have been run, which will extrapolate the halos that vanish within the original catalog.

3.1.4 Studying quenching of SFR

When the halos have been tracked as far as possible, an orbital analysis can be done. For this, I will first develop the orbital analysis code part of the VELOCIraptor package, which aims to find orbiting halos and the properties of their orbits.

The SURFs simulation will be matched to observations from a spectroscopic survey of 300,000 galaxies known as the Galaxy And Mass Assembly (GAMA) survey. This is done by creating the galaxy and group catalogues for both the SURFs simulation and the GAMA survey, which contain all the galaxies and describe the satellites belonging to each cluster group. By using the mass of the galaxies and their respective stellar masses, the catalogues from the SURFs simulation can be matched to the observations from GAMA to see if the observations can reveal if these satellites are quenched or not.

From this, one can also study the quenching process in simulations such as how long the satellites take to quench (quenching timescales). We can then see if the parameters of its orbit, e.g. the time since the galaxy has become a satellite, can determine if a satellite has been quenched or not. Hence for this, we would need to study a variety of orbits and their quenching timescales.

3.1.5 Alter Semi-Analytic Models

Since galaxy formation involves complex processes that require a lot of computation, astrophysicist have come up with a computationally cheap tool to simulate them. This tool is known as a Semi-Analytical Model (SAM), where a SAM populates the dark matter halo merger trees with galaxies and then uses analytical approximations to describe the various astrophysical processes that the galaxies go through in their lifetime (Lacey, 2001).

Tracking of "orphan" galaxies

Satellite galaxies can lose their halo when they are within another halo, where they become disrupted and can no longer be found by the halo finder. This is due to the dark matter halo itself being much more diffuse than the central galaxy. As dark matter interacts very weakly with its environment, it experiences no electrostatic friction so it does not clump together like ordinary matter, hence this is why the halo is diffuse and can be stripped before the galaxy even merge (Guo et al., 2011). When the satellite halo is stripped, the galaxy become "orphaned". Currently when this happens, the trajectory and lifetime are determined from different approaches in SAMs. One approach is where the satellite is assumed to merge immediately when the subhalo is lost, thus there are no orphan satellite. Since the satellites are lost far away from their parent (merging) galaxy, this is a very unphysical approach. Another approach is to define an analytical orbit from the position and velocity of when the satellites become an orphan, which are then continually decreased until the orphans merge with the central galaxy. The final approach is that the position and velocity for the orphan galaxy are determined from the single most gravitationally bound dark matter particle when the subhalo is lost. While the last two approaches are more physically motivated, they would still involve making a lot of assumptions e.g. the mass lost rate. Some SAMs even use a combination of these approaches (Pujol et al., 2017).

But with the improved tracking of the orphan galaxies proposed by this project, they can be tracked well inside their parent halos so estimates will no longer need to be made on how long it will take to merge. Thus we will be able to test and see how

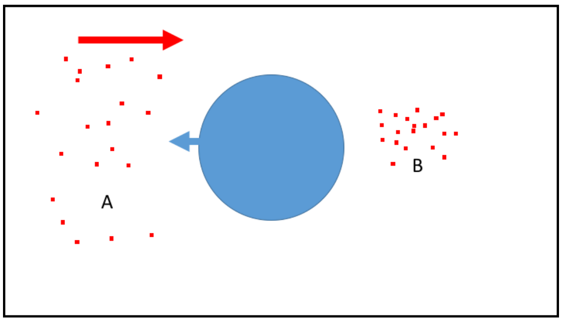


Figure 1: This diagram explains how dynamical friction works. The red arrow shows the direction of motion of the surrounding particles (some are shown in red), and the blue one shows the direction of motion of the halo, represented by the blue circle. Once the halo has passed through the particles that are moving from point A to point B, the particles become denser at point B. The dynamical friction is due to the halo having a stronger gravitational interaction with the particles at point B than at point A so it feels a "gravitational drag".

good the current SAMs treatment of orphans is and provide a better model for them to use.

3.1.6 Non-radiative hydrodynamical simulations

This can also be taken a step further where the results of what we have learnt are applied to non-radiative hydrodynamical simulations. This is where the N-body simulation of dark matter particles also contains adiabatic gas – gas that only transfers energy through work – so very few processes are simulated, hence it is cheaper than doing a full hydrodynamical simulation. Through this, we can more realistically follow what happens to the gas than the prescription that SAMs use. It will also give us a more realistic estimate of the effect on gas reservoirs arising from processes such as ram pressure stripping etc.

This simulation can then be compared to the dark matter only (N-body) simulation to see the effects of adding gas into the simulation on processes such as dynamical friction timescales. Dynamical friction happens when a halo moves through the surrounding particles. Its gravity causes the particles to clump together, but not strong enough to bind them to the halo. Once the halo has pass through these particles, the tighter clump of particles causes a net gravitational force which opposes the motion of the halo and causes it to slow down. All these is shown in figure 1. This phenomenon is known as dynamical friction and it typically occurs when a halo is inside a larger host halo where there are more particles in its environment. The dynamical friction timescale is the time between entering the hosts environment and finally merging with the host (Gan et al., 2010).

How is this project original

This PhD will use the SURFS suite of simulations and data from the GAMA survey, both of which have never been used to study the orbits of satellites. This will enable us to probe down to much lower stellar masses than in previous studies. For this, the much more refined halo finder, VELOCIraptor-STF, is used since it is able to track halos well along their orbit of their parent halo. In the few cases that this does not track well, a different method of halo ghosting is used to track the satellites even further. All of these means that we will have the most accurate treatment of subhalo orbits within these simulations. This has many applications but I will focus on the process of quenching and on studying the effects of adding gas into the simulation, which has never been done before. This project intends to redefine how halo orbit tracking is done.

How does it address an important problem

The environment which a galaxy is in plays a crucial role in its evolution and from its orbital evolution, we can determine what sort of environment the galaxy is in. Thus by using the most accurate treatment of subhalo orbits, we will be able study how the environment affects the evolution of the galaxy. This new approach will allow us to focus on physical processes rather than the uncertainty in subhalo's orbit.

How is this project significant

We will be making an orbit catalog which can be used when subhalos are lost on a certain orbit and distance. This will be useful since many of the complex processes that the galaxy undergoes heavily depend on the orbit and distance of the satellite, so the current SAMs prescriptions of orphaned satellites do not match up to what physically happens. Hence we propose to develop, the most accurate description of what then happens to the satellite can be used until they eventually merge.

3.2 Progress so far

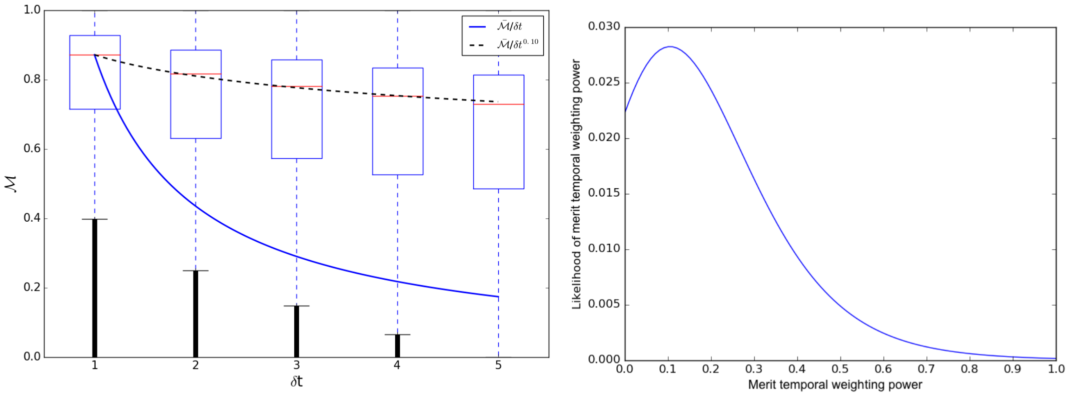
3.2.1 Optimising the VELOCIraptor parameters

When the PhD project started, both VELOCIraptor and Treefrog were not optimized to study orbits. It was found that the settings in VELOCIraptor were not optimal and some halos were disappearing far away from the halo that they are merging with. To rectify this problem, its parameters were evaluated and tuned accordingly.

The minimum halo size parameter sets the minimum number of particle where a further search for other halos are conducted. In this search, the halo is split up into cells so a further search can be done in each of the cells. A clump of particles are then identified as a halo when they meet the minimum number of particles. All these were found to cause some subhalos to not be identified. After much testing, the minimum number of particles and the minimum cell number were adjusted from 200 to 100 particles, and 16 to 8 cells respectively. Thus the minimum halo size parameter is 800. These numbers have been found to provide a more thorough search of subhalos.

3.2.2 Optimising the TreeFrog parameter

Another part of my 6 month project was to optimize the parameter of the halo linker known as Treefrog, which is the code that links up halos across snapshots.



(a)

(b)

Figure 2: The left panel shows the distribution of the merits for each of the snapshots, where the box shows the upper and lower quartiles and the red line represents the median. The black points shows the outlier values. The various fittings to the medians values to follow the evolution of the median merit values with time are also shown in the plot. The right panel shows the likelihood after doing a MCMC test to find the best Merit temporal weighting power

In the simulation, a halo that is identified as being the donor halo of the particles is known as a progenitor. Due to merging, this can mean that a halo has multiple progenitors since the particles from a donor can be split across multiple halos. Thus to select the best-matched progenitor, a merit function is used. The merit function has the functional form

$$\mathcal{M} = \frac{N_{sh}^2}{N_1 N_2}, \tag{1}$$

where $\mathcal{M}$ is the merit function, N_1 is the number of particles in the halo to be linked, N_2 is the number of particles in the halo to be matched and N_{sh} is the shared particles between the halos. There is also additional weighting that is applied to the merit, which is to divide it by the difference in time (snapshot) between the halos to be linked. This has the form:

$$\mathcal{M}_{\mathrm{t}} = \frac{\mathcal{M}}{\Delta t} \tag{2}$$

where $\mathcal{M}_{\mathrm{t}}$ is the temporally weighted merit and Δt is the time difference between the halos which are to be linked. It is weighted so that the merit favors halos which are closest in time to the halo to be matched with, so halos would not be linked to a better-matched halo in a more distant snapshot. This means that it stops halos from being linked over long periods of time. However, the impact of implementing this "penalty" had not been tested so part of the project was to analyze it.

To analyze this, the natural evolution of the median merit was investigated as as a function of difference in snapshot to the halo to be linked across (δt) as shown in figure 2a. This shows how the value of the merit changes as a function of how many snapshots halos are linked over. The median values are used since they show a much better representation of the distribution. This is because the mean is easily skewed by poor merit values, but the median is much less affected.

The median merit values have also been fitted to see how the merit values evolve through

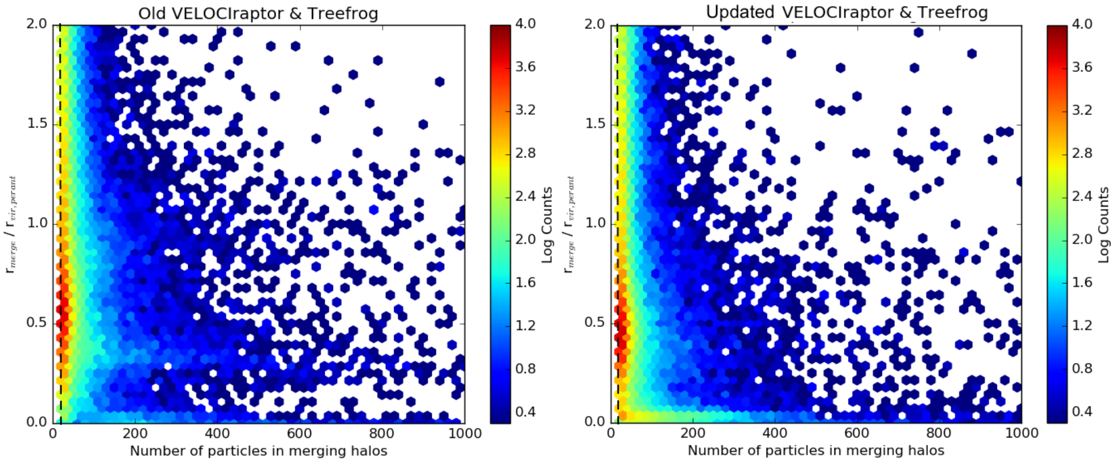


Figure 3: This plot shows the ratio of the radius of the merger to the parents virial radius ($r_{merger}/r_{virial,parent}$) against the number of particles in the merging halo (N_{part}). The coloration shows the log number of counts within each bin

time. The solid blue line in Figure 2a shows the original penalty applied and it can be seen that it does not match well with the evolution of the merit. To find the best fitting to the evolution of the merit a likelihood test was done to find out the best value for the power law to raise the temporal weighting to as shown in figure 2b, with the best value found to be $\sim 1/10$. This means that when the merit values are compared, they are done so with their natural evolution, so halos found at different snapshots can be compared on equal footing.

3.3 Results so far

After applying the updates to VELOCIraptor and Treefrog, a plot of the ratio of the radius which the merger happens (r_{merger}) to the parent halo virial radius ($r_{virial,parent}$) against the number of particles in the halo (N_{part}) is shown in Figure 3. The virial radius defines the spherical region which has density 200 times the background density (Coe, 2010). From the figures it can be seen that updates to VELOCIraptor and Treefrog have resulted in more subhalos being identified close to the parent halos center (small $r_{merger}/r_{virial,parent}$) in addition to more halos being tracked to when they reach the particle limit of 20 particles, as shown by the dashed line.

Compare to other halo finders

To compare how good this method is at identifying the subhalos well inside the viral radius, the result is compared with that of other halo finders. For this test, the halo finder known as Amiga Halo Finder (AHF) (Knollmann & Knebe, 2009) & (Gill et al., 2004) will be used. For a fair comparison, the halo finders were run on exactly the same simulation box using their default settings. To find when the merger happened, the same analysis code was used for different halo finders to make the comparison as fair as possible.

Figure 4 shows the ratio of r_{merger} to $r_{virial,parent}$ as a function of N_{part} for AHF. It can be seen that VELOCIraptor is able to be track more subhalos well inside the viral radius of the host halo compared to the other halo finder. Being able to trace the halos well inside the parent halo is very useful for tracing their orbits since it enables a much more thorough study of the processes that happen.

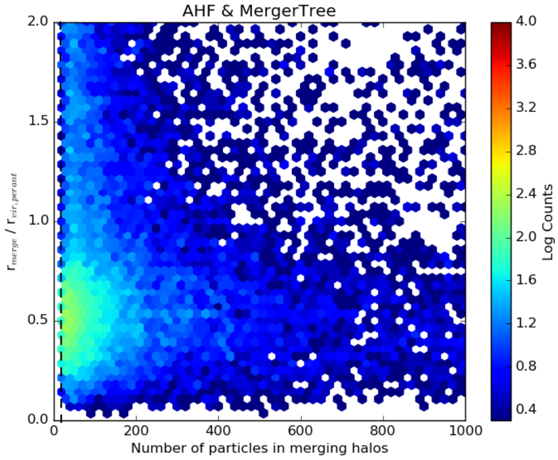


Figure 4: This shows the same plot as in figure 3 but for the halo finder known as AHF,

Although VELOCIraptor does a much better job of tracing the halos after the implementation, to make sure that all the possible orbit properties are extracted, the halo's particles will be "ghosted" where they are continually tracked even though they are no longer identified as a halo in the VELOCIraptor catalog. This is where a less strict unbinding criterion is used than what VELOCIraptor applies so that more particles are likely to be kept and can be traced further in its orbit.

4 Research Project Details

4.1 Confidential information

This project does not require the collection of confidential or sensitive information.

4.2 Intellectual Property

The SURFs suite of simulations data is intended to be released under a public license, so will be free and publicly available for anyone to use.

I will be working an developing code for this project and this will be free and publicly available for anyone to use. This will mean I will use good coding practicing, plus making sure it is well documented and the test that are done are reproducible. This project I have been modifying VELOCIraptor/ TreeFrog, which is a publicly available code and has a MIT Open Source Initiative license [1].

4.3 Fieldwork

I declare that I have read and understood the University field work and insurance policies.

[1] https://opensource.org/licenses/MIT

4.4 Facilities

My research will mostly be done at UWA. I will also be using the PAWSEY Supercomputing Center[2] and the National Computational Infrastructure[3] (NCI).

4.5 Statistical component

This project does include a statistical component, which I have a background in. I have taken several courses in statistics as a undergrad. I will also be enroled in the course *Computationally Intensive Methods in Statistics (STAT4063)*, which will help me with advanced statistical techniques I will need to use and how to use it on computers.

4.6 Skills audit

For my current project no additional skills are needed, since I have some background in using simulations from my undergraduate and my masters project, in addition to other research projects I have been part of. I have also attended the Astroinformatics school as part of the 11th annual ANITA workshop in February 2017, which helped teach me computational skills.

I will be using more statistics later in my project and for this I am taking STAT4063 - Computationally Intensive Methods in Statistics, which should provide me with the statistical methods which I shall need.

I am keen to attend any other useful workshops or training that will help improve my computational, communication and research skills.

4.7 Research project communication

The results of this project will be submitted for publication in at least 3 papers in well-known refereed research journals which are intended to have a high impact factor, such as Month Notices of the Royal Astronomical Society [4] and the Astrophysical Journal [5]

The results of this will be presented a national and international conference such as the Astronomical Society of Australia Annual science meeting[6] either, as a poster or a talk . I have already presented my preliminary results at the 11th annual ANITA theory workshop[7] and the Mock Perth: Challenge for Simulations meeting[8]

[2] `https://www.pawsey.org.au/`
[3] `https://nci.org.au/`
[4] `http://mnras.oxfordjournals.org/`
[5] `http://iopscience.iop.org/journal/0004-637X`
[6] `http://asa.astronomy.org.au/asm.php`
[7] `https://asa-anita.github.io/workshop2017/`
[8] `http://www.caastro.org/event/2017-mockperth`

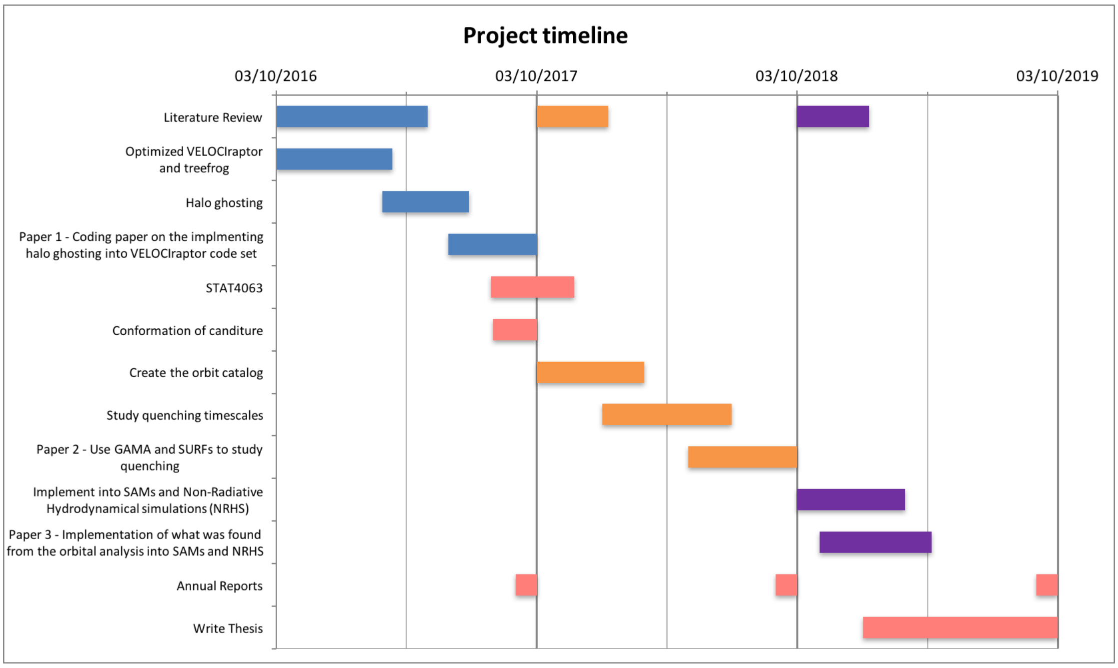


Figure 5: This shows the projected timeline of this PhD, where each project is colored in either blue, orange or purple and the dates for the GRS and the confirmation of candidature are shown in red.

4.8 Approvals

No approvals are required for this project

4.9 Data Management

The data that I produce will be stored on the ICRAR-UWA servers, which has its own backup. This data is not intended to be made publicly available, but this may change.

4.10 Research project plan

During the PhD candidature period a set of milestones should be achieved for the confirmation of candidature and the award of the degree. Figure 5 shows a time-line chart of these milestones.

5 Research Project Support

5.1 Research Training Plan

The research training plan is also shown shown in figure 5 , which shows the dates for the

5.2 Confirmation of Candidature

The following designated tasks are needed to complete the Confirmation of Candidature

Tasks	Due Date
Annual Report	30/9/2017
Confirmation of canditure	30/9/2017
Academic Conduct Essentials (ACE)	Completed
6 point unit	Taking STAT4063
A substantial piece of writing	Draft of a paper

5.3 Working hours

I expected to work 40 hours per week to finish this project.

6 Budget

The budget is shown in Appendix A. The main sources of funding are the Astronomical Society of Australia (ASA) [9], Research collaboration award (RCA), the Graduate Research School (GRS) and the School of Physics & astrophysics . The provisional items are shown in green where they depend on securing the grants.

7 Supervisors

Principle and Co-ordinating supervisor: Dr Aaron Robotham (40%)

Dr. Robotham is a Senior Research Fellow at ICRAR, and his area of expertise is observational astronomy and simulations. Dr. Robotham will ensure that everything I do is physically motivated. As Co-ordinating supervisor, he will administer the Graduate Research School requirements.

A/Prof Christopher Power (40%)

A/Prof. Power is the Computational Astrophysics group leader and is a expert on numerical simulations. He will give me great insight into simulations and how to run them.

Dr Pascal Elahi (20%)

Dr. Elahi is the author of the 6D Friends-Of-Friends code called VELOCIraptor, which is the code I have been modifying for this project. He is an expert on computational astrophysics and has been part of many comparison projects for numerical simulations which involve many research groups around the world.

Weekly meeting will be held where I will give updates of progress in the research project and revisions are suggested.

[9] `http://www.asa.astronomy.org.au/`

References

Abadi M. G., Moore B., Bower R. G., 1999, Monthly Notices of the Royal Astronomical Society, 308, 947

Avila S., et al., 2014, Monthly Notices of the Royal Astronomical Society, 441, 3488

Baldry I. K., Glazebrook K., Brinkmann J., Ivezic Z., Lupton R. H., Nichol R. C., Szalay A. S., 2004, The Astrophysical Journal, 600, 681

Binney J., Tremaine S., 2011, Galactic Dynamics: (Second Edition). Princeton University Press

Brown T., et al., 2017, Monthly Notices of the Royal Astronomical Society, 466, 1275

Coe D., 2010, arXiv:1005.0411 [astro-ph]

Collaboration P., 2016, Astronomy & Astrophysics, 594, A13

Davies L. J. M., et al., 2016, Monthly Notices of the Royal Astronomical Society, 455, 4013

Elahi P. J., Thacker R. J., Widrow L. M., 2011, Monthly Notices of the Royal Astronomical Society, 418, 320

Gan J., Kang X., Hou J., Chang R., 2010, Research in Astronomy and Astrophysics, 10, 1242

Gill S. P. D., Knebe A., Gibson B. K., 2004, Monthly Notices of the Royal Astronomical Society, 351, 399

Guo Q., et al., 2011, Monthly Notices of the Royal Astronomical Society, 413, 101

Knollmann S. R., Knebe A., 2009, The Astrophysical Journal Supplement Series, 182, 608

Lacey C., 2001, The Physics of Galaxy Formation, 222, 273

Larson R. B., Tinsley B. M., Caldwell C. N., 1980, The Astrophysical Journal, 237, 692

Pujol A., et al., 2017, arXiv:1702.02620 [astro-ph]

Searle L., Zinn R., 1978, The Astrophysical Journal, 225, 357

Springel V., et al., 2005, Nature, 435, 629

Wetzel A. R., Tinker J. L., Conroy C., van den Bosch F. C., 2013, Monthly Notices of the Royal Astronomical Society, 432, 336

Wetzel A. R., Tinker J. L., Conroy C., van den Bosch F. C., 2014, Monthly Notices of the Royal Astronomical Society, 439, 2687

Wheeler C., Phillips J. I., Cooper M. C., Boylan-Kolchin M., Bullock J. S., 2014, Monthly Notices of the Royal Astronomical Society, 442, 1396

8 Appendices

Appendix A

Description	Years cost incurred			Source				
	Year 1	Year 2	Year 3	School	ICRAR PG:10200436	GRS	ASA	RCA
Travel costs								
Travel to ANITA workshop*	$1,250.00				$1,250.00			
Travel to ASA meeting		$1,500.00		$500.00			$1,000.00	
Travel to international meeting			$4,000.00	$1,500.00	$650.00	$1,850.00		
Overseas colaboration			$5,000.00					$5,000.00
Research communication/ publication								
Registration ASA meeting		$280.00			$280.00			
Subtotals	$1,250.00	$1,780.00	$9,000.00	$2,000.00	$2,180.00	$1,850.00	$1,000.00	$5,000.00
Total								$12,030.00
Total less provisional items								$1,250.00