PhD Research Proposal

Probing the co-evolution of galaxies and their environment over the last 8 billion years

Jessica E Thorne

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Supervisors: Dr. Aaron Robotham, Dr. Luke Davies, Dr. Sabine Bellstedt, and Prof. Simon Driver

Abstract:

Over the past two decades, the local Universe has been probed in unprecedented detail with surveys such as the Galaxy and Mass Assembly (GAMA) Survey and the Sloan Digital Sky Survey (SDSS). These surveys have allowed us to explore how stellar mass and star formation are distributed, and to understand how these properties correlate with galaxy environment in the local Universe. However, the galaxies we observe in the local Universe were not shaped by current processes, but by the factors that drove galaxy evolution over the preceding 10 billion years. Little is known about the processes and environmental changes that shaped galaxy evolution over the intermediate stages of their lifetimes, and ultimately resulted in the distribution of galaxies we see in the local Universe. The new Deep Extragalactic VIsible Legacy Survey (DEVILS) will explore these processes at earlier cosmic times and provide insight into the evolution of the mass and star formation distributions, and environmental effects driving their changing distributions. As part of my PhD I am leading the production of a number of the core data products of the DEVILS project, such as stellar masses, star-formation rates and star-formation histories. I will then exploit these state-of-the-art datasets to investigate the evolution of star formation in the Universe and the impact of environment on star formation processes.

1 Galaxy Evolution since the beginning of time

Our understanding of galaxy formation and evolution has been greatly enhanced over the past three decades due to the large amounts of data from multi wavelength imaging and spectroscopic surveys (e.g., GAMA; Driver et al. 2011; Liske et al. 2015 and SDSS; Abazajian et al. (2009)). Through the combination of this new observational data and theoretical tools, a consistent picture has emerged, where the star formation rate density peaked approximately 3.5 Gyr after the Big Bang, at redshift $z \approx 1.9$, and has declined exponentially at later times. It is also now clear that approximately half the stellar mass observed today was formed before redshift $z = 1.3$ (Madau & Dickinson, 2014). Figure 1 is taken from the cosmic star formation history (cSFH) review by Madau & Dickinson and shows the increase of the cosmic star formation rate density since the big bang (on the right side of the figure) and the subsequent decrease since redshift $z = 2$.

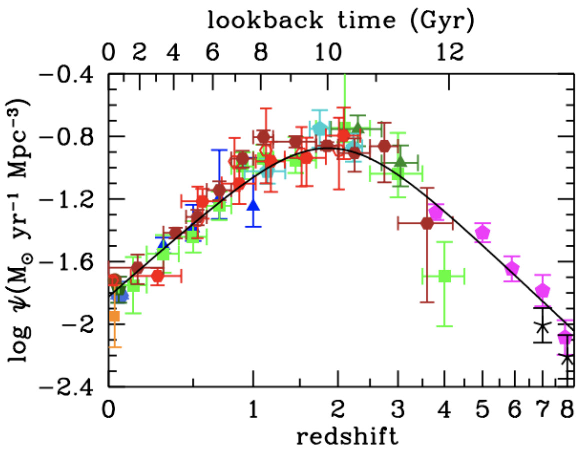

Figure 1: Figure 9 from Madau & Dickinson (2014) showing the decline in cosmic star formation rate density since $z = 2$ through a compilation of FUV + FIR measurements from a variety of sources.

Although it is now well understood that the star formation rate density of the Universe has decreased since $z \approx 2$, measuring the underlying factors which govern this evolution and the growth of galaxies is problematic. There are two dominant mechanisms that drive galaxy evolution: mergers (e.g. Robotham et al. 2014) and star formation. However, secondary effects such as AGN (Kauffmann et al., 2004), gas supply (Tacconi et al., 2013) and local (Davies et al., 2015) and large-scale (Peng et al., 2010; Davies et al., 2019b) environment also have a significant impact on the evolution of galaxies. It is the varying contribution of these processes over the history of the Universe which have lead to the distribution of galaxies we observe today.

In the local Universe, galaxies can be broadly classified into two populations: blue star-forming systems and red quiescent systems, which have little to no active star formation (e.g. Blanton et al. 2003; Kauffmann et al. 2003, 2004; Baldry et al. 2004; Taylor et al. 2015). When selected in a variety of different ways, including the specific star-formation rate or star-formation rate vs stellar mass plane (see Davies et al. 2016b, 2019a), these populations show clear bimodality, suggesting that the transition from star-forming to quiescent is potentially fast and occurs over a broad range of stellar masses. Current observational evidence suggests that there are two dominant modes of galaxy quenching; secular quenching and environmental quenching. Secular quenching can occur in all galaxies irrespective of external processes and is correlated with the internal properties of a galaxy. Secular quenching appears to be more pronounced at higher stellar masses ($M_* > 10^{10} M_\odot$, see Fang et al. 2013; Bluck et al. 2014; Bremer et al. 2018) but simulations also require gas outflows that inhibit star formation in the lowest-mass galaxies in order to reproduce the observed distribution of low-mass systems (Dekel & Silk, 1986). The second mode of quenching is driven by a galaxy's local environment. Over-dense environments such as clusters, groups, and even close pairs (see Patton et al. 2011; Robotham et al. 2014; Davies et al. 2016a, 2019b) can either remove or inhibit the supply of gas required for ongoing star formation, leading to a quenching event. Environmental quenching is more likely to affect intermediate-to-low-mass galaxies ($M_* < 10^{10} M_\odot$, see Davies et al. 2019a) and is found to correlate with local galaxy density and position. Environmental quenching should only affect satellites and will not generally affect central galaxies that sit at the centre of their groups and are typically the most massive galaxy in their group. As such, we may expect centrals and satellites to undergo different quenching mechanisms and display different passive fractions (fraction of galaxies which are quenched, e.g. Peng et al. 2010, 2012; Robotham et al. 2014; Grootes et al. 2017).

From studies of overdense environments in the local Universe it is clear that the environment of a galaxy directly impacts the formation of stars, but this can be to both increase the star formation or to strip gas and induce quenching events. There have been a number of recent studies investigating the removal of gas in 'jellyfish' galaxies (see Poggianti et al. 2017; Bellhouse et al. 2017; Fritz et al. 2017; Gullieuszik et al. 2017; Moretti et al. 2018; Vulcani et al. 2020). The so-called jellyfish galaxies are objects exhibiting disturbed morphology, mostly in the form of tails of gas stripped from the main body of the galaxy. This stripping is due to the movement of the galaxy through a dense environment which causes large amounts of gas to be stripped from the galaxy. One of the studies on a jellyfish galaxy has shown increased recent star-formation in the outer regions of the galaxy due to interactions with a galaxy cluster before a second interaction caused the stripping of gas and subsequent quenching (Fritz et al., 2017). Another study on a different jellyfish galaxy showed that the onset of the stripping occurred in the last 500 Myr, completely stripping the outer gas and quenching star formation (Gullieuszik et al., 2017).

1.1 The Deep Extragalactic VIsible Legacy Survey

To measure a galaxy's environment a spectroscopic survey with high completeness is required as photometric surveys lack the required precision in the redshift measurement. Previous surveys such as the Galaxy And Mass Assembly (GAMA; Driver et al. 2011, Liske et al. 2015) Survey and the Sloan Digital Sky Survey (SDSS; Abazajian et al. 2009) have reached the high completeness required for measuring environment in the local universe. These surveys have only been able to provide information of the recent evolution of galaxies and structure (in the last $\sim$3 Gyr). To observe galaxies at earlier times, a number of deep and narrow surveys like the redshift Cosmic Evolution Survey (zCOSMOS; Lilly et al. 2009) have been carried out. These surveys have allowed for precise redshift measurements out to higher redshifts ($z \approx 1$) but lack the high completeness required to perform group science.

The Deep Extragalactic VIsible Legacy Survey (DEVILS; Davies et al. 2018), which is currently observing using the Anglo-Australian Telescope (AAT), is designed to fill the gap between the highly complete, but low redshift surveys and the high redshift but sparsely sampled surveys. DEVILS is designed to have a higher median redshift ($z_{\mathrm{median}} \approx 0.6$) than surveys like GAMA but also reach the same level of completeness as GAMA ($> 85\%$) to recover the large scale structure and galaxy groups out to higher redshift.

As part of the survey $\sim 20,000$ spectroscopic redshifts will be obtained/ compiled in the D10-COSMOS field, a sub-field of the well studied Cosmic Evolution Survey field (COSMOS; Scoville et al. 2007). This region is covered by an extensive array of imaging and spectroscopic data ranging from x-ray to low-frequency radio continuum observations. Recently we have re-measured photometry for the D10 field across 22 bands from the FUV-FIR using the ProFound source-extraction code (Robotham et al., 2018). This new photometry catalogue is described in detail in Davies, Thorne et al. (in prep.) and, in combination with the spectroscopic measurements from DEVILS, will form the base data set for my project.

The D10/COSMOS field currently is the most complete of the DEVILS fields and is complete down to a magnitude of 20 in the Y-band as shown in Figure 2. This is a significant improvement on previous spectroscopic campaigns in the COSMOS field (e.g. zCOSMOS; Lilly et al. 2009). Due to COVID-19 delays, we are now expected to reach required completeness ($Y_{\rm mag} = 21.2$) in the D10 field by early 2021. Alongside the spectroscopic redshifts obtained by DEVILS, there are many high quality photometric redshift catalogues with a very high precision, $\sigma_{\Delta z/(1+z_s)} = 0.007$, and a low catastrophic failure fraction, $\eta = 0.5\%$. This will allow us to begin fitting the spectral energy distributions of DEVILS galaxies before we have reach the desired completeness, and will also allow us to push to fainter galaxies.

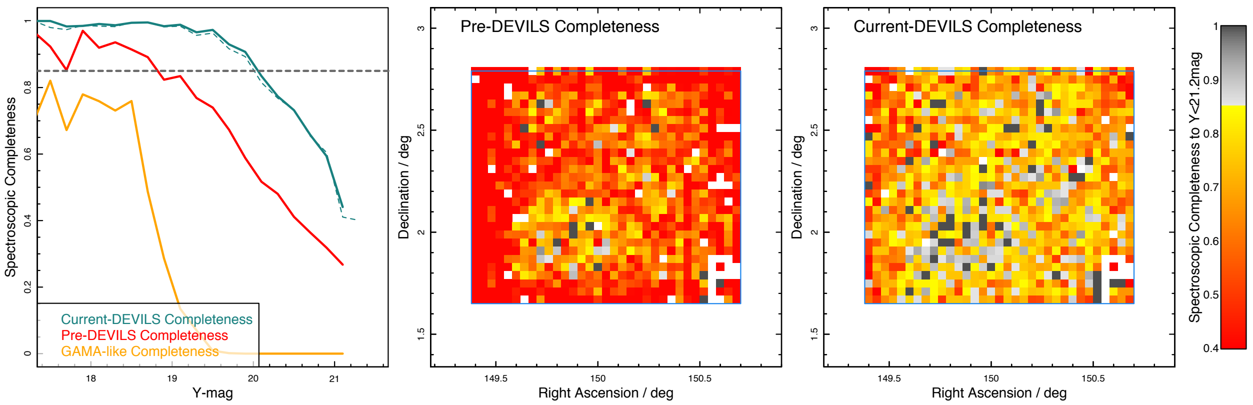

Figure 2: Current DEVILS spectroscopic completeness in the D10 region. Left: completeness as a function of Y-mag for current DEVILS (green), pre-DEVILS (red, largely zCOSMOS) and GAMA-like (orange). The dashed horizontal line displays the completeness required for detailed group and pair environment studies (0.85 completeness). Middle and Right: the spatial completeness to Y<21.2 targets pre-DEVILS (middle) and currently (right) in 0.2×0.2 deg bins. The colour bar is scaled such that bins with > 0.85 completeness are coloured in greyscale.

2 Spectral Energy Distributions

As galaxies cannot be experimented upon or observed over time scales long enough to watch them evolve, astronomers must develop other ways to fully understand the underlying physics that governs galaxy properties. One of the best tools for understanding galaxy properties is through the analysis of their spectral energy distribution (SED). Galaxies emit radiation over the full electromagnetic spectrum, from gamma-rays to radio, due to contributions from stellar populations, dust, active galactic nuclei, gas, and other radiative processes. The different processes each dominate and contribute at different wavelengths, leaving their imprint on the shape of the galaxy spectrum. For example, the birth of stars often dominates galaxy emission in the ultraviolet while re-emission of absorbed light by dust often dominates the infrared. This distribution of energy (photons) emitted as a function of wavelength is called a Spectral Energy Distribution (SED) and can be the primary source of information about properties of spatially unresolved galaxies. Figure 3 shows a representative SED for a mock galaxy. It can be seen that there are clear features in different wavelength regimes that are dominated by different processes. Many of the fundamental properties of galaxies are encoded in their SEDs and include the star formation history (SFH) and current star formation rate (SFR), stellar metallicity, total mass in stars, and the physical state and quantity of dust and gas. Some of these properties are easier to measure from SEDs than others, and each provides important clues regarding the formation and evolution of galaxies. It is precisely these quantities, measured from the SEDs of galaxies, that have provided the foundation for our modern understanding of galaxy formation and evolution.

Over the past several decades considerable effort has been devoted to extracting information from

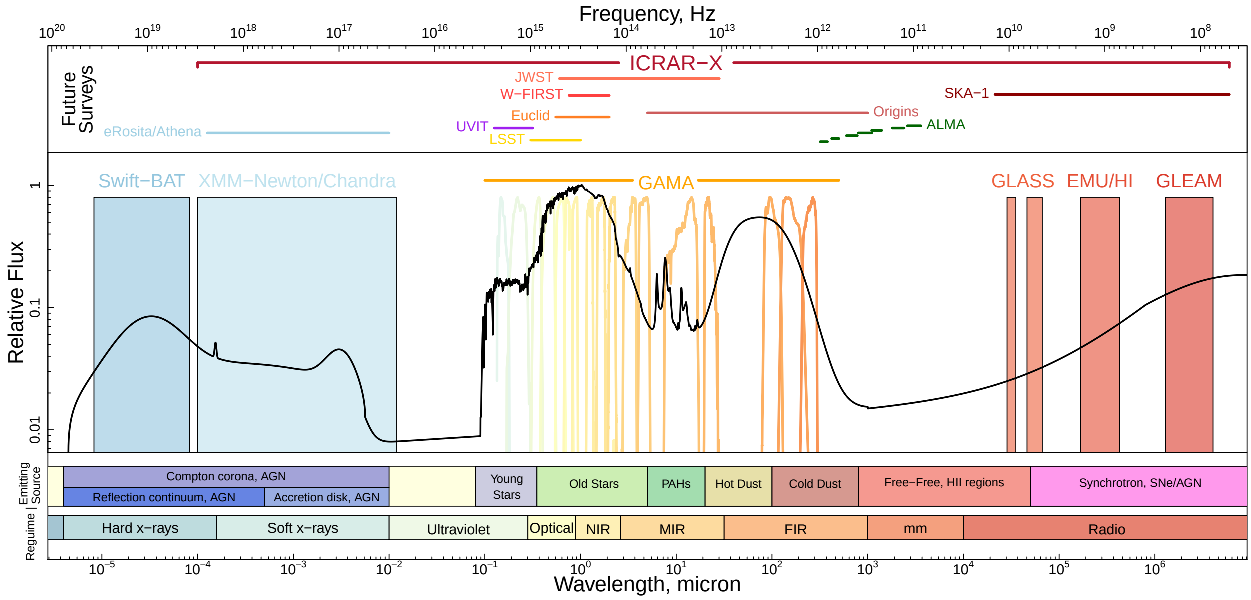

Figure 3: An example spectral energy distribution for a theoretical galaxy highlighting the regimes where different processes contribute and the future surveys that will probe each regime. Credit: Luke Davies

SEDs, exploiting information from the far-ultraviolet (FUV) to the far-infrared (FIR). Extracting information from SEDs is achieved through the fitting of synthetic or empirically-derived templates that model the contribution from stars, dust, gas and active galactic nuclei. The most studied and well understood templates are those relating to a galaxy's stellar population. Since the early 1970s considerable progress has been made to evolve from combining mixtures of stars in ad hoc ways (Spinrad & Taylor, 1971) through to more sophisticated 'stellar population synthesis' (SPS) techniques, which used the substantial progress made in stellar evolution theory to constrain the range of possible stellar types at a given age and metallicity (Charlot & Bruzual 1991; Bruzual & Charlot 1993, 2003; Maraston 1998, 2005; Vazdekis 1999 etc).

These stellar models for the FUV-Optical portion of SEDs were developed in parallel to those for the dust contribution in the infrared regime (e.g., Draine & Lee 1984; Zubko et al. 2004) and it is only recently that models have been developed to simultaneously and self-consistently predict the FUV through FIR SEDs (e.g. Da Cunha et al. 2008; Noll et al. 2009). Since the development of these models and subsequent 'SED fitting codes', SED fitting has become one of the most commonly used methods to understand galaxy properties on large scales. There now exists a plethora of options when it comes to SED fitting with each option being tailored for specific purposes. These include codes like MAGPHYS (Da Cunha et al., 2008), CIGALE (Noll et al., 2009), BAGPIPES (Carnall et al., 2018), Prospector (Leja et al., 2017) and ProSpect (Robotham et al., 2020).

2.1 SED Model Components

Each of the SED fitting codes listed above relies on a collection of pre-existing models that are combined in differing ways to model a galaxy SED. These models can be broken down to those that relate to the stellar component, the dust component and sometimes an active galactic nuclei component.

The ultraviolet (UV) to infrared (IR) spectra of all galaxies arises from stellar light, either directly or reprocessed by the gas and dust of the surrounding interstellar medium (ISM). Thus the UV-to-IR SED contains a large amount of information about the stars of a galaxy, such as the stellar mass and current star formation rate. However, to extract such information, models are necessary in order to connect physical properties of the galaxy with the observed SED. A galaxy contains a large number of stars ranging from numerous, low-luminosity, low-mass stars, to the bright, short-lived massive stars. These stars are distributed in metal content [1] (metallicity) and age ranging from when the galaxy first formed to newly born stars. Modelling these ranges of masses, ages, and metallicities is vital to extracting an accurate star formation history for each galaxy.

The metallicity of galaxies is known to also affect the derived physical properties, as higher stellar metallicity causes galaxies to appear redder than galaxies with lower stellar metallicities. Theoretically, the gas-phase metallicity of galaxies is known to change over time due to the creation of metals in stars and their expulsion into the interstellar medium through supernova explosions, but also through the accretion of gas from the intergalactic medium and outflows of gas from the galaxy. Up until now, SED fitting codes have implemented very simplistic and un-physical treatments for metallicity with most codes adopting a constant but free metallicity (i.e. where the metal content does not evolve with time). This has very large effects on the derived physical properties and star formation histories of galaxies, and has been shown by Bellstedt et al. (in prep) to completely change the recovered cosmic star formation history for a large sample of galaxies.

Interstellar dust is a component of nearly all galaxies, especially those that are actively star-forming. Dust plays a dual role in the modelling of SEDs, as it obscures light in the UV-NIR and it emits light in the FIR. Generally these two aspects are often modeled independently of one another. Dust grains obscure light by both absorbing and scattering starlight. The models that describe this attenuation depend on the star-dust geometry, grain size distribution, etc., in a complex manner but several general rules of thumb can be stated. The most common way to model dust geometry is through the use of a homogeneous foreground screen. This screen approximation produces an attenuation curve that depends only weakly on the total dust column density. This assumption allows for a simpler model for dust but does not account for differential dust and star geometries that are clearly visible in resolved galaxies, such as bulges, disks and dust lanes. The use of a single dust attenuation curve for analyzing a wide range of SED types is therefore without theoretical justification.

Finally, some galaxies are known to host an active galactic nuclei (AGN) component which can be brighter over a large fraction of the electromagnetic spectrum than the other galaxy components. AGN can be difficult to model due to the large range of spectral outputs, and many possible geometries. As AGN fitting is difficult and AGN are known to be rare, I will not be including an AGN component in my SED templates.

2.2 ProSpect

For my analysis of galaxy SEDs, I will be using the ProSpect SED fitting code (Robotham et al., 2020). The reasons for using ProSpect over other existing codes (e.g. MAGPHYS, CIGALE, Prospector, BAGPIPES etc.) are that ProSpect allows for entirely flexible implementations of the star formation history and metallicity history parameterisations. Previous SED fitting codes do not implement evolving metallicities and assume constant metallicity over the lifetime of the galaxy (e.g. Leja et al. 2019; Carnall et al. 2019). However, as discussed above, appropriately modelling the metallicity evolution of galaxies is vital to accurately recovering the overall growth and decay of star formation density in the Universe (Bellstedt et al. in prep). Figure 4 shows a schematic of some of the popular SED fitting codes and the input models and templates, with ProSpect highlighted.

As validation of ProSpect Robotham et al. (2020) tested one of the star formation history implementations included in ProSpect against star formation histories extracted from the Shark semi-analytic model (Lagos et al., 2018) and found that it is not possible, using the implemented star formation

[1] in astronomy metals are any element that is not hydrogen or helium

histories, to capture the fine details in the simulated star formation or metallicity history, but that the general smoothed form is certainly recoverable with the implemented model. As part of this analysis they also found that the closed box implementation of metallicity evolution can recover the general trend of the Shark metallicity histories. Bellstedt et al. (submitted) also found that ProSpect was able to recover the observed cosmic star formation history using star formation histories extracted for $\sim 7,000$ galaxies in the nearby Universe.

3 Aims

Based on the above discussion, the main aim of this project is to use ProSpect to recover properties of galaxies in the DEVILS D10 Early Science Field and begin investigating the evolution of galaxies over the last eight billion years. The D10/COSMOS field is one of the most studied regions of the sky and measurements of galaxy properties have already been carried out for large numbers of galaxies in the field. However, using the new flexible implementation of metallicity in ProSpect and the new photometry and spectroscopic redshift catalogues developed as part of DEVILS, we believe we can extract the most accurate star formation rates, stellar masses, metallicities, and star formation histories for these objects with a higher median redshift and higher completeness than ever before.

The main goals for my PhD project will be to:

- Test the accuracy of the ProSpect derived galaxy parameters and use the new measurements to remeasure the stellar mass function and star-forming main sequence out to $z \approx 1$ (see Muzzin et al. 2013; Lee et al. 2015).
- To compare the cosmic star formation history derived by ProSpect for higher redshift galaxies to that derived by Bellstedt et al. (submitted) for a low redshift sample of galaxies and to understand the differing contributions to the overall shape by galaxy type.
- To investigate the effect of environment on the star formation histories of galaxies to understand whether centrals and satellites have undergone different evolutionary processes (e.g. see Davies et al. (2019b)).

4 Methodology

The main aim of this project is to derive the star formation histories for $\sim 20,000$ galaxies and understand how different galaxy types contribute to the cosmic star formation history. This will involve:

- Performing tests to establish whether the current ProSpect star formation history parameterisation and priors will accurately recover the star formation histories for galaxies in the DEVILS sample.
- Running ProSpect on a sample of more than $20,000$ galaxies from the DEVILS D10 region, and potentially a similar number of galaxies from the other DEVILS regions, to extract their star formation history, current star formation rate and stellar mass.
- Combining extracted stellar mass and star formation rate measurements to provide updates to the commonly used stellar mass function and stellar mass vs. star formation rate plane out to $z \approx 1$. I will also use the ProSpect fits for the GAMA sample presented in Bellstedt et al. (submitted) to remeasure the stellar mass vs. star formation rate plane at low redshift to combine with the higher redshift measurements from DEVILS.

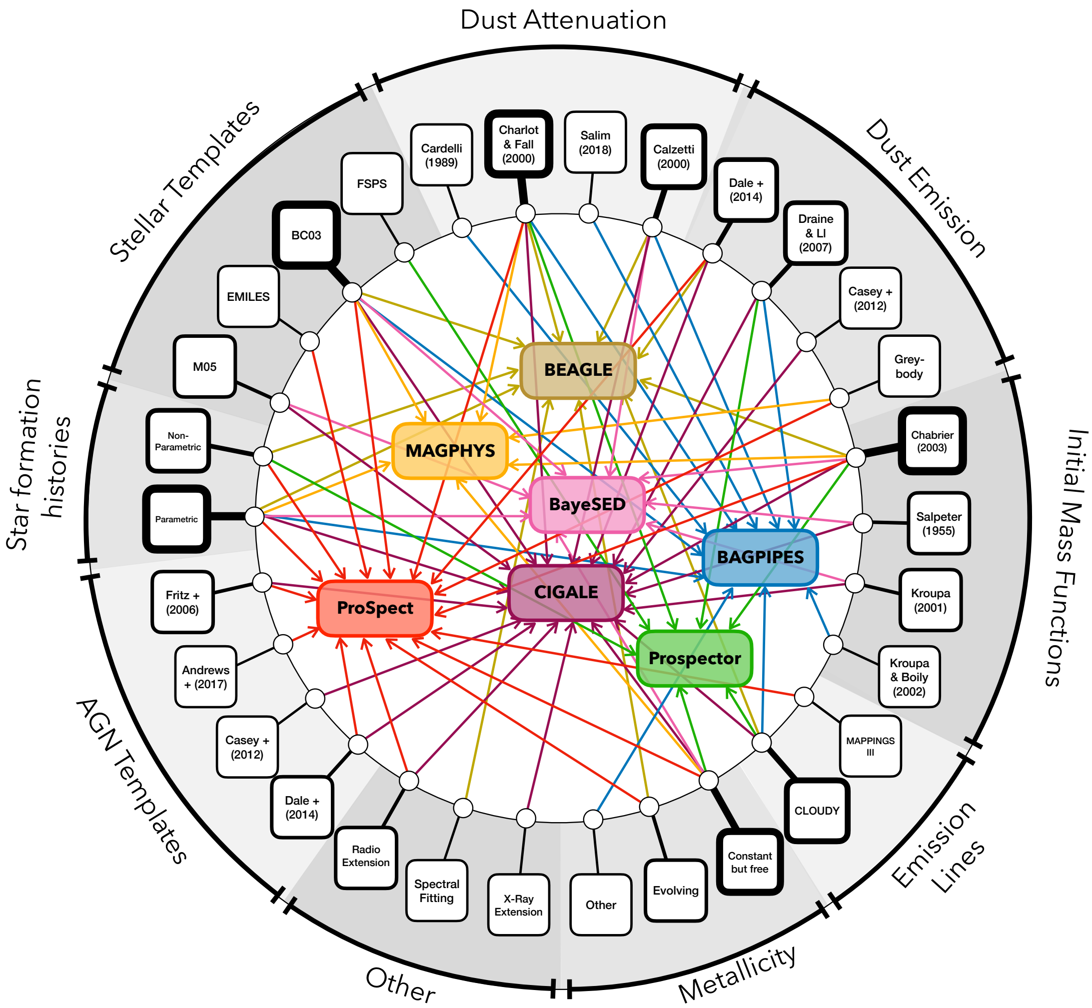

Figure 4: Schematic depicting some of the most popular SED fitting codes and the input models including stellar templates (models used to describe the emission from stars), the initial mass functions (used to describe the mass distribution of stars that form from a single birth cloud), dust models, AGN models, and the parameterisations of the star formation and metallicity histories. The red represents ProSpect (Robotham et al., 2020), dark gold is BEAGLE (Chevallard & Charlot, 2016), blue is BAGPIPES (Carnall et al., 2018), purple is CIGALE (Noll et al., 2009; Boquien et al., 2019), green is Prospector (Leja et al., 2017), orange represents MAGPHYS (Da Cunha et al., 2008), and pink is BayeSED (Han & Han, 2012, 2014, 2019). Additional stellar template references: BC03 refers to the templates from Bruzual & Charlot (2003), EMILES are the templates from Vazdekis et al. (2016), M05 is Maraston (2005) and FSPS is Conroy et al. (2009).

- Combining the extracted star formation histories to reconstruct the cosmic star formation history and to use the galaxy morphologies derived by Hashemizadeh et al. (submitted) to understand trends with galaxy type.
- Using derived environmental metrics to compare star formation histories for central and satellite galaxies at fixed halo and stellar masses.
- Investigating the distribution of sources on the stellar mass vs. star formation rate plane based on environment, recent star formation history, structure and morphology.

As none of the DEVILS fields are currently at the required completeness for group science, a DEVILS group catalogue describing the environment of each galaxy does not exist yet. This means that there is no group catalogue that can be used for comparison. As such, the final paper/project in this plan is provisional. There are a number of alternative directions the third paper could be taken in. These include using other environmental metrics that are not as robust as group catalogues such as density measurements or looking at close pairs of galaxies to begin probing the effects of environment on the star formation of galaxies. There also possibilities for the third paper including using the derived stellar mass functions at different redshifts to constrain merger rates or adapting ProSpect to be able to extract quenching timescales so we can better understand the transition from blue star-forming galaxies to red quiescent galaxies. There is also the possibility to extend the analysis of the cosmic star formation history out to higher redshift ($z \sim 4$) using the 3D-HST sample (Momcheva et al., 2016; Brammer et al., 2012). A decision on this project will be made near the completion of my second paper, and will be based on the current state of the ongoing DEVILS' spectroscopic sample.

5 Current Status

ProSpect has already been used to recover star formation histories for a large sample of galaxies in the nearby universe ($z < 0.06$) from the GAMA survey and has been used to begin probing the evolution of galaxies since the beginning of time. Bellstedt et al. (in prep) used the ProSpect fits for a sample of $\sim 7,000$ galaxies with $z < 0.06$ to forensically recreate the cosmic star formation history over the lifetime of the Universe, and investigated trends with galaxy morphology and mass. This work by Bellstedt et al. will allow for direct comparison between the CSFH obtained for objects in the local Universe to the CSFH I will obtain at higher redshifts ($z > 0.3$).

The initial months of my PhD were devoted to helping prepare the required photometry data for the early science data release of the DEVILS survey (Davies, Thorne et al., in prep.). This involved regrouping large fragmented galaxies and developing the far infrared photometry pipeline. This data release is vital for my proposed project as it will be the base data set for everything I do. This paper is nearly complete and will be submitted in the next few months.

After the base photometry was complete I started working on the implementation of the SED fitting for the DEVILS sample. To ensure that the configuration of ProSpect was appropriate for our sample I performed a number of tests:

- I tested the flexibility of the star formation history parameterization and ensured that it was able to extract the stellar mass and current star-formation rate for input mock galaxies.
- I tested the effect of the dust and metallicity parameters and the implementation of metallicity in ProSpect
- I compared the outputs of initial ProSpect runs with known relations such as the stellar-mass vs. star-formation rate plane, the mass-metallicity relation and stellar mass functions. These comparisons and new measurements will also be included in my first paper. Figure 5 shows the

current status of the stellar mass vs star-formation rate plane derived using the ProSpect fits and comparison with previous measurements from Lee et al. (2015)

- I investigated the ability to freely fit the redshift for objects where we only have photometric redshifts and whether allowing for a free redshift to also be fit was beneficial for the derived quantities.

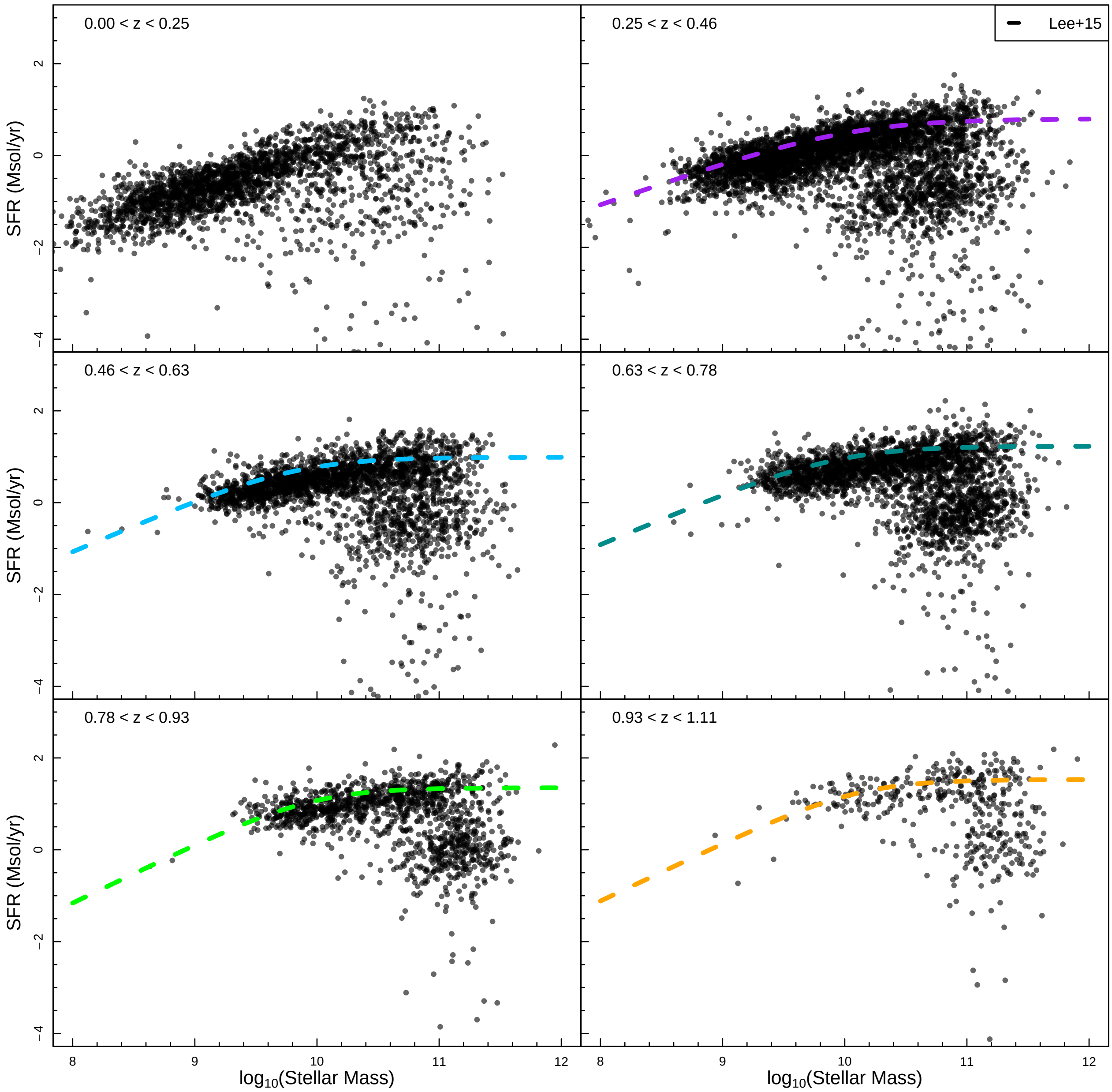

Figure 5: The stellar mass vs star-formation rate plane as derived using ProSpect with previous measured relations from Lee et al. (2015)

After we were satisfied that the ProSpect outputs were reasonable I have fitted a large sample of DEVILS galaxies and extracted stellar mass and star-formation rate estimates for systems in the D10 Early Science field. These estimates form the basis for the first paper of my PhD and will be used to allow other members of the DEVILS team to start working on their own science projects using my data.

6 Research Project Details

6.1 Confidential/Sensitive and Intellectual Property information

My work does not require confidential or sensitive information. The DEVILS data set is still in progress and I will contribute to some of the data files. These will initially be released internally to the DEVILS team before being publicly released via AAO data central [2]

The ProSpect and ProFound codes used for my PhD are publicly available on github. Proper citations and credit will be given to all authors whose work or tools I use. If any of this changes I will inform the Graduate Research School.

6.2 Fieldwork Information

Most research work will be conducted directly at the UWA node of the International Centre for Radio Astronomy Research (ICRAR/UWA). There will be a chance for me to travel domestically to carry out DEVILS observations at Siding Spring Observatory in New South Wales. When this happens, I will follow the protocols set out by the GRS.

6.3 Facilities

The facilities at ICRAR/UWA are sufficient for the purposes of my research. Time on external supercomputers will be required for the large scale fitting of galaxies. We have secured 100,000-300,000 CPU hours on Pawsey Centre's ZEUS for 2020 for this project and other ProSpect related projects. We also have access to the OzStar supercomputer at Swinburne for this work.

6.4 Statistical Component

A large portion of this project requires statistical analysis. All of the statistical analysis will be conducted using the R programming language. I have completed the Astrostatistics and Computational Astrophysics unit as part of my Masters degree and have a reasonable understanding of the statistics required for my project.

6.5 Skills Audit

For the purposes of the PhD project, I have listed the skills which will be required and my corresponding proficiency at each in Table 1

6.6 Research Project Communication

I will defend my research proposal to a 3-member ICRAR-based panel in June 2020. My progress will be presented to the same panel on an annual basis in the form of a seminar (mid January in each year between 2021 - 2023), at which point I will receive constructive feedback on my work and items to improve. I plan to present my thesis as a series of papers. For each, I have provided a brief overview of their content below.

Paper 1: Extracting Stellar Masses and Star Formation Rates for the D10 Field using ProSpect

This paper will present the method of fitting using ProSpect and the sample selection for the objects I will use in my subsequent two papers. This paper will also present and describe the state-of-the-art stellar mass and star formation rate catalogues that will be part of the core DEVILS data release. This

[2] `https://datacentral.org.au/`

Research Skill	Current Rating	Evidence	Desired Rating
Understanding and application of relevant data collection and analysis methods including experience carrying out observations	Competent	Undergraduate and Masters level study in physics including data analysis. Masters, studentship and pre-PhD projects all involved a large amount of data processing. Have also completed four nights of remote observing	Proficient
Identifying and accessing appropriate bibliographic resources	Competent	Completed Masters thesis	Proficient
Use of information technology relevant for research	Competent	Masters level high performance computing unit; experience with python, FORTRAN, R and Mathematica	Proficient
The principles and conventions of academic writing	Basic	Masters Thesis and Studentship report	Competent
Ability to constructively defend research outcomes at seminars and conferences	Basic	Masters Thesis Seminar and conference talk at ESOz 2020	Competent

Table 1: Outline of skills required for PhD project and my current perception of competence in each

paper will also contain comparisons to previous stellar masses and star formation rates derived for this field using other methods. This paper will also include updates to the stellar mass function and stellar mass vs star formation rate plane which will be tabulated for other astronomers to use.

Paper 2: A forensic reconstruction of the cosmic star formation history at moderate redshift using ProSpect

This paper will utilise the star formation histories obtained from the ProSpect fits used for my first paper to forensically reconstruct the cosmic star formation history in different redshift bins. This reconstruction of the cosmic star formation history at higher redshifts will be compared to similar measurements at low redshift by Bellstedt et al. (submitted). This paper will also present the cosmic star formation history of different galaxy types including galaxy mass and morphology using the morphologies derived by Hashemizadeh et al. (submitted).

Paper 3: Star formation trends with environment at moderate redshift

The current plan for this paper is to compare the star formation histories obtained with environmental metrics to understand the influence of environment on galaxy evolution. As we currently have not reached the desired completeness in the D10 field and we do not currently have a group catalogue for the DEVILS survey, the content of this paper is tentative. Contingencies for this third paper are discussed in Section 4.

6.7 Approvals

No research approvals regarding ethics or otherwise are required for my project at this time. If approvals are required in due course, the GRS will be contacted.

6.8 Data Management

The data I require for my project will be primarily stored on my personal laptop and on the ZEUS supercomputer at the Pawsey Centre. Everything stored on my personal laptop is also backed up to dropbox. The catalogues created for the DEVILS survey will also be stored on AAO data central[3].

6.9 Research Project Plan

Figure 6 displays a Gantt chart with the currently planned research project tasks and estimated timelines for each. It also shows the deadlines and timelines for items in the research training plan.

7 Research Training

To complete my confirmation of candidature I have agreed to fulfill the following tasks. These tasks are also included in the Gantt chart shown in Figure 6.

- AACE1000 Academic Conduct Essentials: Completed 2015 (undergraduate degree)
- UWA Diagnostic English Language Needs Assessment (DELNA): Completed 28/01/2020
- Project Proposal Report: to submit July 2020 (due 11th July 2020)
- Project Proposal Presentation: Completed 24th June 2020
- Coursework to a total of 6 points: To complete November 2020 (UWA/ICRAR requirement).
- Substantial piece of writing at the appropriate conceptual level: To complete substantial draft of first paper by 12th January 2021.
- Annual Progress Report: To complete by 12th January 20201
- Annual Progress Seminar: To complete in January 2021

Working Hours

My regular working hours will nominally be 7am - 4pm from Monday to Friday with variation as required, with time allocated for lunch.

8 Budget

I have been allocated $1250 EMS faculty for the purchase of a new laptop, $1850 from the GRS for international conference travel, and up to $3250 from ICRAR to aid with expenses. I have joined the ASA which will provide $1000 for international travel and travel assistance to the ASA Harley Wood Schools and conferences. Table 2 contains my projected expenses.

Table 2: Estimated expenses during my Ph.D.

Item / Description	Estimated Cost	Amount Available	Funding Source
Computer	2500	1250	EMS
		1250	ICRAR
Domestic Travel	1250	1250	ICRAR
International Travel	3500	1000	ASA
		1850	GRS
		650	ICRAR
Poster Printing	100	100	ICRAR

[3] https://datacentral.org.au/

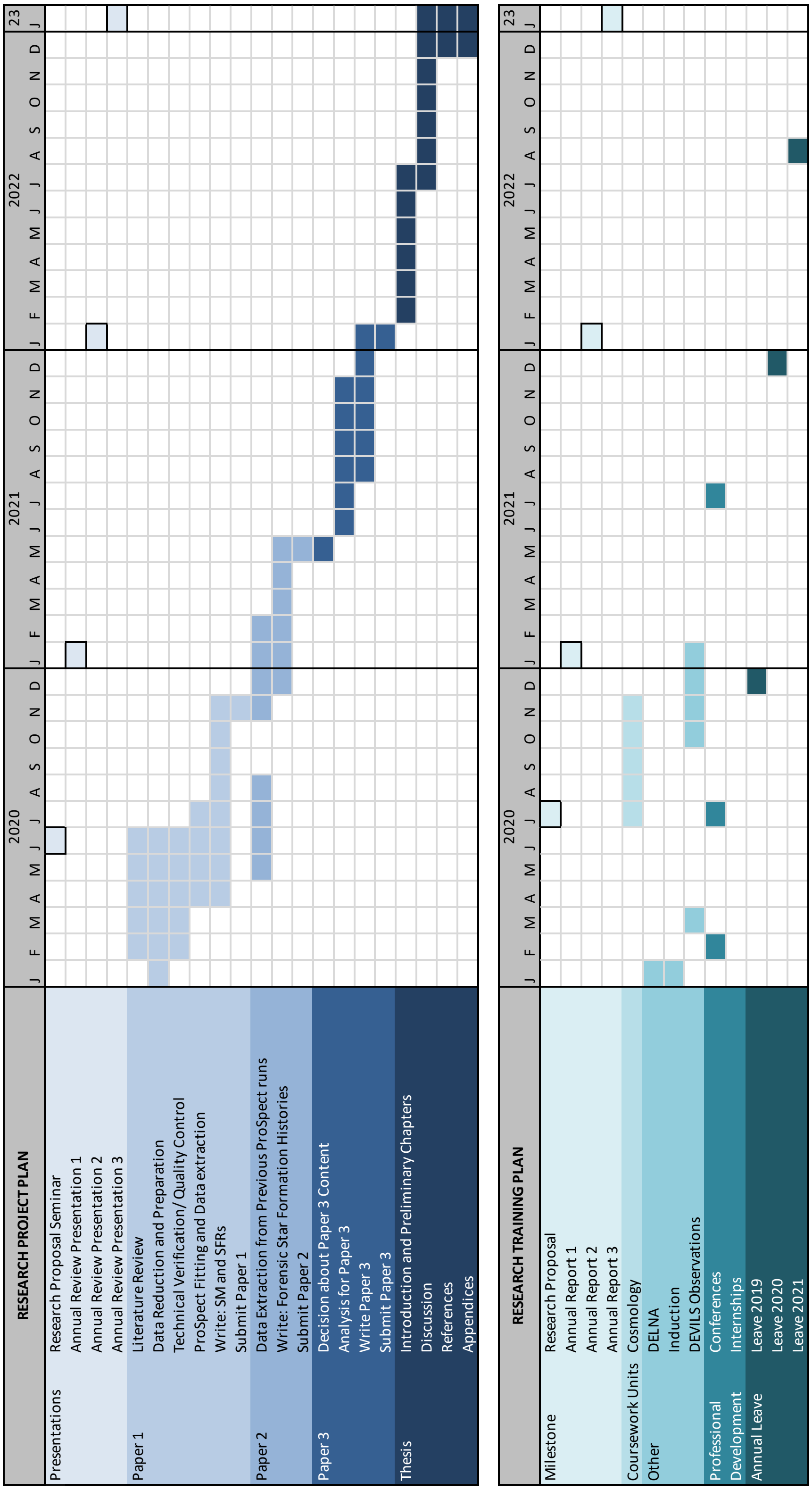

Figure 6: The timeline plan for my PhD. The top panel represents the project tasks, and the bottom panel represents the research training and candidature requirements.

9 Supervision

- Dr Aaron S. G. Robotham: Principal Supervisor. [40%] Will provide guidance on SED fitting and analysis as he is the principal developer of ProSpect, an SED fitting code. Dr Robotham and I will meet on a weekly basis (often in conjunction with Dr Sabine Bellstedt and Dr Luke Davies).
- Dr Luke J. M. Davies: Co-Supervisor. [30%] Will provide guidance on working with and creating future data products for the DEVILS survey as he is the lead researcher of the survey.
- Dr Sabine Bellstedt: Co-Supervisor. [20%] Will provide additional guidance on SED fitting and analysis of the cosmic star formation history as she has completed similar work to the work proposed here using the GAMA survey at lower redshift.
- Prof. Simon P. Driver: Co-Supervisor. [10%] Professor Driver is the lead researcher of the GAMA survey and will provide guidance on linking to GAMA. We will meet as required.

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