# Australian Time Allocation Committee

**Proposal for Time**

**Semester:** 2022A
**Reference:** A/2021B/13
**Submitted:** No

| Investigator | Affiliation | Observer | Student | PhD Thesis | Supervisor |
|---|---|---|---|---|---|
| Bryant, Julia | University of Sydney | Yes | No | No | |
| Robotham, Aaron | University of Western Australia | Yes | No | No | |
| Fraser-McKelvie, Amelia | University of Western Australia | Yes | No | No | |
| Battisti, Andrew | Australian National University | Maybe | No | No | |
| Hopkins, Andrew | Australian Astronomical Observatory | Maybe | No | No | |
| Lopez-Sanchez, Angel | Australian Astronomical Optics, Macquarie University | Yes | No | No | |
| Koribalski, Baerbel | CSIRO Astronomy & Space Science | No | No | No | |
| Catinella, Barbara | ICRAR/UWA | Yes | No | No | |
| Groves, Brent | ICRAR, UWA | Yes | No | No | |
| Miszalski, Brent | AAO Macquarie | Maybe | No | No | |
| Foster, Caroline | Sydney institute for astronomy, University of Sydney | Yes | No | No | |
| Power, Chris | University of Western Australia | Maybe | No | No | |
| Lagos, Claudia | University of Western Australia | Yes | No | No | |
| welker, charlotte | University of Western Australia | Maybe | No | No | |
| da Cunha, Elisabete | Australian National University | Maybe | No | No | |
| Wisnioski, Emily | Max Planck Institute for Extraterrestrial Physics | Yes | No | No | |
| Taylor, Edward | Swinburne University of Technology | Yes | No | No | |
| Poetrodjojo, Henry | University of Sydney | Yes | No | No | |
| van de Sande, Jesse | University of Sydney | Yes | No | No | |
| Bekki, Kenji | University of Western Australia | Maybe | No | No | |
| Kewley, Lisa | Australian National University | Maybe | No | No | |
| Cortese, Luca | University of Western Australia | Yes | No | No | |
| Davies, Luke | University of Western Australia | Maybe | No | No | |
| Drinkwater, Michael | University of Queensland | Yes | No | No | |
| Meyer, Martin | University of Western Australia | Maybe | No | No | |
| Varidel, Mathew | University of Sydney | Maybe | No | No | |
| Owers, Matt | Macquarie University | Yes | No | No | |
| Colless, Matthew | Australian National University | Maybe | No | No | |
| Brown, Michael | Monash University | Maybe | No | No | |
| Scott, Nicholas | University of Sydney | Yes | No | No | |
| McDermid, Richard | Macquarie University | Yes | No | No | |
| Sharp, Rob | Australian National University | Yes | No | No | |
| Sweet, Sarah | University of Queensland | Yes | No | No | |
| Bellstedt, Sabine | University of Western Australia | Yes | No | No | |
| Vaughan, Sam | University of Sydney | Yes | No | No | |
| Brough, Sarah | University of New South Wales | Yes | No | No | |

| | | | | | |
|---|---|---|---|---|---|
| | | Yes | No | No | |
| Driver, Simon | University of Western Australia | Maybe | No | No | |
| Oh, Sree | Australian National University | Yes | No | No | |
| Barone, Tania | ANU-RSAA | Yes | No | No | |
| Grasha, Kathryn | Australian National University | Yes | No | No | |
| Bland-Hawthorn, Joss | University of Sydney | Maybe | No | No | |
| For, Bi-Qing | International Centre for Radio Astronomy Research | Yes | No | No | |
| Riding, Bruce | University of Sydney | No | No | No | |
| Wong, O. Ivy | University of Western Australia | Maybe | No | No | |
| Couch, Warrick | Australian Astronomical Observatory | Maybe | No | No | |
| Wang, Adeline | student | Yes | No | Yes | Scott Croom, Julia Bryant |

**Principal Contact:** Bryant, Julia (Julia.Bryant@sydney.edu.au)

# The Hector Galaxy Survey

The Hector Galaxy Survey aims to to investigate the influence of environment on galaxy evolution with more precision than has has ever been possible with previous of existing integral field galaxy surveys. The combination of large integral field units, called 'hexabundles' giving resolved spectra across a larger field of view in each galaxy, and the highest spectral resolution are unique in the Hector Galaxy Survey. This will enable us to determine the role of detailed large and small scale environment on how galaxies accrete material to form star and build their angular momentum. We request 32 Hector nights and 11 2dF nights for the first semester of the Hector Galaxy Survey.

| | **Dark** | **Grey** | **Bright** |
|---|---|---|---|
| Total number of calendar nights requested this semester | **32** | **11** | **0** |
| Minimum useful allocation this semester | **10** | **5** | **0** |
| Additional nights required to complete project in future | **568** | **10** | **0** |

Number of nights already awarded to this project: 0

Type of proposal (open or paid): Open

| **Preferred dates:** | **Earliest** | **Latest** |
|---|---|---|
| | 01 Sep 2021 | 01 Dec 2021 |

**Impossible Dates:**

**Special scheduling constraints:**

## Instrumentation

**Instrument 1:**

| | |
|---|---|
| Gratings: | 580V, 1000R |
| Central Wavelengths (Ã…): | 4800, 6830 |
| Blaze Wavelengths (Ã…): | 4800, 6830 |
| Beamsplitter: | 570nm dichroic |
| Nod & shuffle: | No |
| Originating catalogue used for astrometry of targets: | GAMA |
| Do guide stars and targets share the same catalogue astrometry?: | No |
| Other requirements: | |

**Instrument 2:**

| | |
|---|---|
| Instrument Name: | Hector - not actually a visitor instrument but not listed in the instrument list until after commissioning this se |
| Focus: | Prime f/3.3 doublet |
| Director's permission: | Yes |
| Other requirements: | |

## Related proposals (in this semester)

| Telescope/satellite | Title of the proposal |
|---|---|

## Previous related proposals

| Reference | Title | Allocation | Percentage useful | Comments (Data ok? publications? etc.) |
|---|---|---|---|---|
| A/2019B/17 | The Hector Cluster Redshift Survey | 0 | | |
| A/2020A/17 | Probing the outskirts of rich galaxy clusters: where and when is star formation quenched? | 0 | | |
| A/2020B/24 | Probing the outskirts of rich galaxy clusters: where and when is star formation quenched? | 7n | 50% | Heavily weather affected. |
| A/2021A/15 | Probing the outskirts of rich galaxy clusters: where and when is star formation quenched? | 0 | | |

## Description of the proposal for the general public

Where a galaxy grows up in the Universe can influence what it turns out to look like, and how it spins. Whether a galaxy is within large scale structures such as filaments or massive clusters, or on its own in voids can set how easily it can accrete stars and gas to grow in size and angular momentum. Using the new Hector instrument on the AAT, we are beginning what will be the largest '3-D' survey in the world, giving a spectrum at each point across each of 15,000 galaxies. The high resolution of the new Hector instrument and large field of view across the galaxies means we can measure not only the galaxy compositions but the rotations and dynamics in their gas and stars as well. This is crucial to understanding how galaxies grow.

# 1 The Hector Galaxy Survey Science Case

*The ATAC Chair has granted an extra two pages for this proposal to outline the big picture of the full Hector Galaxy Survey (Hector-GS) as well as the focus of the 2021B semester. Therefore AAL requested it be submitted in the long-term programs section so the extra pages would be accepted even though Hector is not offered for long-term proposals yet. While Hector is not yet listed as an instrument available for this semester because it will be commissioned in 2021A, Chris Lidman has confirmed we can apply now and 2021B time will be on a shared-risk basis.*

## 1.1 The Hector-GS Overview

*What is the physical basis for the diversity of galaxy properties in the local Universe?* This is the overarching science question driving the Hector-GS. The answer lies in connecting the internal properties of galaxies to the detailed role of their environment. In the Milky Way, dynamics and chemical evolution of stars from GAIA, Apogee and GALAH have identified that accretion from, and interactions with, satellite galaxies have shaped our galaxy. From extragalactic studies, in the past decade there has been a paradigm shift from local and global density-based environment properties to defining environments based on both large-scale structure (filaments, walls, nodes) and where galaxies sit in velocity space. The unique capabilities of the Hector instrument will enable us to tackle this question with the data that cannot be achieved with any other survey. The large survey size and spectral resolution that is a factor of two better than any other comparable instrument, will explore from the high to low-mass end of the stellar mass function with exquisite environmental characterisation. The Hector-GS plans to observe 15,000 galaxies over 6 years, providing a ground breaking data set that maximises the science productivity of the remaining life of the AAT.

The legacy of the Hector-GS will lie not only with the vast and rich data set produced by the survey, but in unique science that cannot be done with any other instrument in the world. SAMI [11, 5, 12] and MaNGA [8] have been the largest IFS surveys to date. However, they lack a combination of the higher spectral resolution which enables stellar kinematics to be measured in a larger fraction and broader diversity of galaxies; the broad range in halo masses required to test the influence of environment, including mapping the large cluster halos out to higher cluster radii; larger IFUs to give resolved spectra of galaxies to a larger galaxy radius; and a larger sample that will allow the key drivers of galaxy evolution to be statistically determined by sub-dividing the sample in physical parameter space with sufficient statistical accuracy.

The Hector-GS has optimised the science synergies with other large Australian projects. Researchers within the ASKAP WALLABY [18] and DINGO (https://dingo-survey.org/) surveys will combine their HI data with the Hector-GS to link gas accretion mechanisms and total gas masses from the inner galaxy regions to the scales probed by HI observations. Also, a working group of simulators are already active in the Hector science team, focused on a range of fundamental questions that can be addressed with the Hector-GS regarding the impact of large-scale structure on galaxy evolution. The Hector-GS regions have been selected to be within the ESO 4MOST WAVES North and South sky areas, which will provide exquisite environmental metrics to confirm the place of our galaxies within local and large-scale structures as well as their kinematic flows (https://wavesurvey.org/).

The Australian community selected the Hector instrument as the next main dark-time instrument for the AAT. Membership of the Hector science team is open to all astronomers working in Australia. The data will deliver a vast array of science to the already 57-strong Australian Hector Science team, drawn from across the country from 8 Universities plus the CSIRO. The team builds from the SAMI IFS team and is expected to outgrow the 140-strong SAMI team once the survey is collecting data.

**Here we request the first observing semester of the Hector-GS**. We will apply for a large program once the instrument is fully commissioned (scheduled from May to August 2021). The main part of the current proposal focuses on observations with Hector that start the full survey, but also enable a number of short term science goals. However, we also request nights with 2dF to complete the redshift measurements for the Hector-GS input catalogue. This relatively small investment is important to enable an unbiased input catalogue and to optimize Hector observations.

## 1.2 Science Justification

The Hector-GS is tailored to enable significantly new science in the following four key areas:

(A) **How is the accretion of gas and angular momentum (spin) influenced by local and global environment?** Cosmic structures over the mega-parsec scale, such as cosmic filaments and clusters where they intersect, strongly constrain the flows and thermodynamics of baryons in their vicinity. Simulations and theory predict that this impacts the accretion onto galaxies, and therefore their spin, structure and more generally their dynamics. The world-leading Australian surveys WALLABY and WAVES (2023+) will map galaxies and their peculiar velocities in the local Universe with unprecedented detail. They will locate the Hector galaxies both in 3D space and dynamically within cosmic flows, permitting the most extensive analysis of correlations between large-scale structure morphology and galaxy-scale dynamics.

SAMI demonstrated the feasibility of such studies through the first detection of the alignment of galaxy spins with filaments [32], but the limited statistical power capped the significance of the results at $\approx 2\sigma$. It also precluded any analysis of cosmic walls, any multivariate analysis (field filaments, filaments in groups, filaments in clusters) and any detailed analysis of the

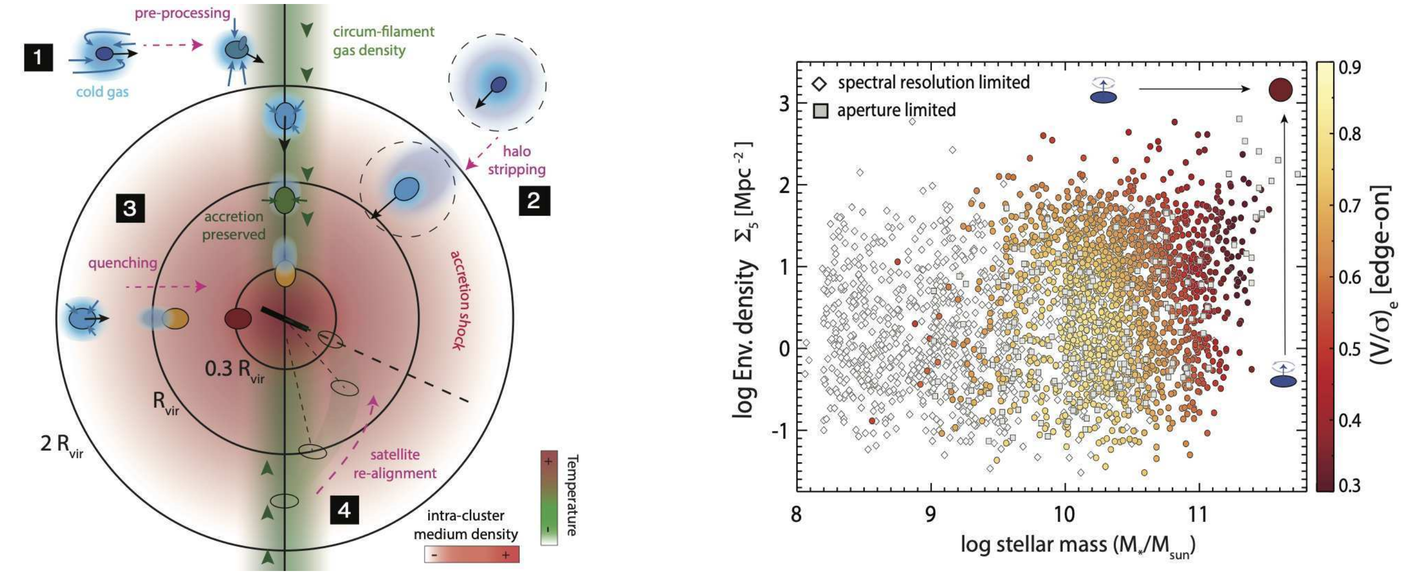


**Figure 1: Left panel: Simulations predict the way filaments from large-scale structure and cluster outskirts cause transitions in galaxy evolution.** 1- Large filaments re-orient inflows, disturb the plane of a galaxy and have a higher merger rate than the field. 2 - Accretion in cluster outskirts deplete outer gas reservoirs of infalling galaxies. 3- Clusters increase quenching through stripping and strangulation but these processes are reduced in intra-cluster filaments. 4- Satellites re-orient their orbit and spin in clusters. Dominant mechanisms are expected to differ depending on galaxy mass *Adapted from [31, 19].* The Hector-GS will have the statistical power and range of environments to robustly test these processes. **Right panel: The impact of stellar mass and environment on the dynamical properties of galaxies.** SAMI successfully revealed the key drivers of dynamical galaxy transformation of *all* morphological types [28]: towards higher stellar mass and denser environments galaxies transform from being rotationally supported to dispersion dominated. However, SAMI's spectral resolution and limited bundle size hamper kinematic measurements for low mass and high-mass galaxies. *The Hector-GS will open up these largely unexplored regimes.*

corresponding kinematic disturbances in the outer parts of galaxies. With its increased sampling, wider field of view and wider covering of clusters up to $2\,R_{\rm vir}$, the Hector-GS will allow for a deep analysis of how filament/wall, filament/group and filament/cluster interactions impact galactic inflows, spin and structure.

Such studies are very timely. Modern simulations predict for instance that cluster outskirts ($0.75 - 2\,R_{\rm vir}$) are regions of multiple transitions, strongly impacting the structure of galaxies (see Fig.1, left panel). It's where satellite galaxies are expected to progressively align their orbit and spin to the central galactic plane, while aligned to the nearby cosmic filament at outer radii [31, 30]. While the orbit transition was detected in the SDSS [33], the spin counterpart requires the power of the Hector-GS.

(B) **Tracing the mass accretion and dynamical evolution of galaxies through utilising Hector's spectral resolution.** The SAMI Galaxy Survey was the first to clearly demonstrate the impact of environment on the stellar-dynamical properties of galaxies (e.g., Fig. 1, right panel). The largest dynamical change is detected for the most massive galaxies ($\log(M_\star/M_\odot) > 11$) in the most extreme environments. Between $9.5 < \log(M_\star/M_\odot) < 11$ the dynamical transformation as a function of both mass and environment is significantly smaller [10, 13, 28]. In this regime, a factor $> 5$ increase in sample size is paramount to understand what physical processes determine a galaxy's morphology and dynamical structure. Nonetheless, the highest impact science is expected to come from the mass regimes currently out of reach of SAMI. Towards low stellar mass (Fig 1, right panel), there are hints that galaxies become more dispersion dominated [see also 14, 27, 2, 3], but this mass regime is currently below SAMI's spectral resolution. The higher spectral resolution of Hector will enable stellar kinematic measurements in a wider range of galaxies than any other survey. Similarly, for the most massive galaxies in extremely dense cluster environments, SAMI's current bundle size restricts measurements to the very core of these galaxies, when the vast majority of accreted material and transformation is predicted to take place at larger radius[$> 2R_{\rm e}$; 26, 4, 25]. It is in these low and high-mass regimes where the Hector-GS will lead to a breakthrough.

Hector will also revolutionise our ability to measure higher-order kinematic signatures that offer a complementary yet unique insight into the orbital structure of galaxies. Measurements from SAMI have resulted in well-cited results for high stellar mass galaxies [29], but the Hector-GS will probe the stellar kinematics of the low-stellar mass population in large numbers for the first time. Detailed Schwarzschild's orbit-superposition models have now demonstrated that higher-order kinematic signatures can efficiently and accurately detect orbital substructures (e.g. counter rotating bulges) without the need of full dynamical modelling [24]. The Hector-GS will yield an unprecedented large sample of galaxies ($N \sim 4000$) where higher-order kinematics can be measured, across stellar mass, morphology, and environment that will enable detailed comparison to simulations [e.g. 21, 26] that relate galaxy formation models to the stellar kinematics, to unravel the formation paths of galaxies as drivers of their present-day physical properties.

(C) **Directly identifying feeding and feedback in galaxies**. The Hector-GS will evaluate the balance of gas supply for star formation in all environments by imaging outflows from kinematic signatures and emission line diagnostics of shocks and AGN. While a limited number of galaxies had the right size and orientation in the SAMI survey to identify galactic winds and outflows [16, 17, 20], the larger IFU imaging fibre bundles called 'hexabundles' and survey strategy in Hector allow for the gas kinematics to be traced to higher effective radii within each galaxy. This, in turn, better captures the velocity structure, including the maximal rotational velocity, and the subtle signs of inflows, outflows and re-accretion at large radii, for a much larger fraction of emission-line galaxies. Our modelling has shown that the higher spectral resolution in the blue will enable multi-component line fitting and distinguishing of AGN outflow signatures in the [OIII]500.7nm emission line, which are ambiguous with the lower resolution IFS surveys.

(D) **Testing the origin of gas and its influence on star formation in galaxies.** The kinematic misalignment of gas and stars is a key tracer of the origin of gas and the impact of gas accretion and mergers on star formation and the build-up of mass. It has been shown with SAMI [7] that the larger IFU size in Hector is needed to map the merger signatures and in-coming accretion from larger radius, which is necessary to constrain galaxy formation models.

The broad interests of the Hector Science team met by this survey also include i) spatially resolving star formation rates, metallicities and stellar ages; ii) tracing galaxy star formation histories from stellar populations iii) Separating the formation histories and mechanisms for the disk and bulge components of galaxies and much more.

### 1.3 Survey Design and Target Selection

Target selection for the Hector-GS will follow a similar philosophy to that of the SAMI galaxy survey, using a selection function described by a series of steps in the redshift – stellar mass plane (see [5] for details). To avoid an overabundance of $L_*$-mass galaxies, we will sparsely select in the mass range $\sim 10^{10} - 10^{11}\,\mathrm{M}_{\odot}$. The final target selection will select 15,000 galaxies at $z \leq 0.1$.

The need for 15,000 galaxies has been carefully set by simulations and experience with the SAMI data. While SAMI detected the first signature of galaxy spin alignments with cosmic filaments [32], the significance was limited to $\approx 2\sigma$ and precluded more detailed analysis. We have determined that with 15,000 galaxies over a wider area, the Hector-GS will not only provide a robust confirmation of this result but will also allow for ground-breaking studies of how galaxy kinematics correlate across the hierarchy of large-scale structure. The wider field of view, covering the outskirts of many of these galaxies, will allow us to integrate properties of galactic-scale inflows, thought to be the missing link between large-scale and galactic scale dynamics, into this analysis.

The Hector-GS will be comprised of a "field" sample and a "cluster" sample in order to observe galaxies from a range of environmental densities. The field sample will target galaxies in two regions: one in the north galactic cap at $\delta \simeq 0°$ (with known redshifts from SDSS, 2dFGRS and GAMA); and a second at $\delta \approx -30°$ in the south galactic cap (with known redshifts from 2dFGRS). These two regions will be observed with un-resolved single-fibre spectroscopy using 4MOST as part of the upcoming WAVES survey from 2023. Photometry for the target selection is based on deep optical KiDS imaging.

The Hector-GS field sample will probe a significant range in environmental densities, from the lowest density voids all the way to the centres of low mass clusters. However, the Hector-GS volume does not contain rare massive clusters ($M_{200} > 10^{14.5} M_{\odot}$). To sample the full range in environment density, the Hector-GS will observe an additional 11 galaxies clusters with $M_{200} > 10^{14.5} M_{\odot}$, which have existing high-quality optical *griz*-band imaging from the Dark Energy Survey [DES; 1]. The Hector-GS will go beyond the cluster science possible with SAMI by covering the cluster outskirts, out to twice the virial radius. This will bridge the density regimes of field and cluster galaxies. These intermediate density regions are a crucial environment for the morphological transformation of galaxies. Thus, the Hector-GS will be the first IFS survey that truly covers the full range of environmental densities, allowing for the most comprehensive investigation of environment-driven galaxy transformation to date.

The 2021B semester Hector observations will include the GAMA G23 region, which has complete redshift coverage needed for the Hector Survey selection. Beyond this semester, the target galaxies in the southern WAVES region do not currently have sufficiently high redshift completeness to carry out the full Hector-GS. This is because the existing redshifts in this field (from 2dFGRS) are incomplete at all magnitudes and preferentially target blue galaxies based on photographic $b_J$ magnitudes [9], leading to biases in the input catalogue available to Hector. Existing photometric redshifts are simply not accurate enough to select our targets: the average uncertainty is $\sigma_z \sim 0.1$ at $z \sim 0$, whereas we require at least two orders of magnitude higher precision to place targets in the appropriate redshift-mass intervals during target selection. We plan for the current missing redshifts to be filled in with short 2dF observations ahead of the following year's observations with Hector in that same region. Once the WAVES survey is underway in mid-2023, it will provide the remaining redshifts.

In 2021B, we are therefore applying for 11 grey nights of 2dF time to fill in the 2dFGRS catalogue in the WAVES South and cluster regions. We will target all galaxies not observed by 2dFGRS down to 17.7$^{\text{th}}$ magnitude in the $r$-band, ensuring the Hector survey input catalogue to be used in future semesters is 100% complete to this magnitude. This matches the depth of the SDSS survey from which we will obtain redshifts in some of the Hector-GS equatorial regions and ensures an adequate target density for tiling the fields with the Hector instrument. These 11 nights of 2dF time will provide enough redshifts to facilitate $\approx 50$ Hector nights in future second half year "B" semesters, and are vital to ensure the viability of the Hector-GS in the forthcoming semesters until the WAVES survey data becomes available.

### 1.4 Plan for Semester 2021B

The Hector instrument has 19 hexabundles on galaxies in each pointing and two that image secondary standard stars for calibration. The Hector-GS aims to target 800 galaxies in this semester in 32 dark/grey nights, with 2 fields per night and 19 galaxies per field (with weather overhead). Our targets this semester are best observed in September, October and November in 10-11 night blocks centred on dark time. To reach 15,000 galaxies, a future request of 100 nights (2,500 galaxies) per year over 6 years is required.

Targets for 2021B will be chosen from the main Hector survey input catalogue, but be specifically chosen to allow key early science results. They will deliver immediate papers on the following 3 science cases:

(1) **The unexpected dynamics of low-mass dwarf galaxies.** Recent results indicate that both low-mass ($\log(M_\star/M_\odot) < 9.5$) spirals and spheroidals have unusual low ratios of $V/\sigma$ as compared to more massive galaxies [14, 27], and break away from fundamental galaxy scaling relations [e.g., Faber-Jackson, $M_\star$-S0.5; 2, 3]. Determining the physical cause for low-mass galaxies to be outliers is currently restricted by 1) a bias towards spheroidal galaxies and those with early-type morphology residing in over-dense cluster environments, and 2) limited spectral resolution in the largest IFS surveys (e.g., ATLAS$^{3D}$, CALIFA, SAMI, and MaNGA). Due to its higher spectral resolution, the Hector-GS will be the first IFS survey to properly measure the stellar dynamics of low-mass galaxies. We will test whether the offset from current dynamical scaling relations is real or whether this is caused by the limited spectral resolution of previous surveys. This first semester will deliberately preference low-mass galaxies and will ensure repeat observations to reach the required depth (typically 2-3 repeats) for these low-mass galaxies occur within this semester. Based on the tiling in these fields this will result in 250 $\log(M_\star/M_\odot) < 9.5$ galaxies in this semester alone.

(2) **Inflows and outflow at higher Re:** While SAMI was able to detect the presence of extra-planar ionised gas likely associated with outflows in edge-on galaxies [17], the spatial extent of these outflows was limited by the small fibre bundle sizes of SAMI. With the larger fibre bundle sizes of Hector we will be able to probe much further out, to trace the radial decline of the outflows and their ionization structure to a much higher order. This semester will intentionally target a set of $\sim 40$ galaxies that have effective radii that are larger than fit in the SAMI hexabundles and preferentially edge-on galaxies where outflows and galactic winds will be more easily detected in ionised gas to the edge of the Hector hexabundles. This number alone will substantially build on the outflows results from SAMI.

(3) **The future fate of ram-pressure affected cluster galaxies:** SAMI targeted galaxies in the central parts of 8 clusters, finding a substantial fraction of recently accreted star-forming galaxies were undergoing outside-in quenching due to the effects of ram-pressure stripping [23]. However, many of these galaxies are only partially quenched, exhibiting ongoing central star-formation. The outstanding question is whether these galaxies are completely quenched at first cluster core passage, as predicted by [22], or whether the central star formation continues for long periods following pericentric passage. The Hector-GS will address this question by measuring the spatial distribution of star formation in galaxies located in the 1-2$R_{200}$ regions. This region is dominated by two distinct galaxy populations: higher velocity galaxies on their first in-fall into the cluster, and lower velocity "backsplash" galaxies that are close to the turn-around radius after a recent cluster core passage [15]. Comparing the resolved star-forming properties of the first time in-fallers, the backsplash, and galaxies in the central virialised regions will provide a strong empirical constraint on quenching timescales following the accretion of a galaxy onto a cluster. This first semester will focus on galaxies located at 1-2$R_{200}$ from a cluster that has SAMI data within $R_{200}$, thereby allowing a complete view from the core to the outskirts of this cluster.

## References

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## 2 Technical Justification

**Instrument setup and exposure times:** Hector uses two spectrographs simultaneously - AAOmega and Spector (the new Hector spectrograph). In both spectrographs the wavelength range is selected to include [OII]$\lambda$3727Å to the [SII] doublet at $\lambda$7424Å for our maximum survey redshift of 0.1. Important lines in between are [NII], [OI], [OIII], Mgb, D4000, Fe lines, H$\alpha$ and rest of the Balmer series. AAOmega will cover a wavelength range of $3700 - 5700$Å with the 580V grating giving a resolution of $R \sim 1700$ in the blue arm. The 1000R grating on the red arm will cover $6300 - 7400$Å at $R \sim 4500$. Spector has a fixed instrumental resolution of 1.3Å from $3727 - 7761$Å delivering $R \sim 3460$ at 4500Å and $R \sim 5000$ at 6500Å.

Both spectrographs will use the same exposure times because they are observing galaxies simultaneously. The exposures are set to achieve S/N sufficient to measure stellar velocity dispersions out to 1 effective radius, and $H\alpha$ emission line out to 2 effective radii. The Hector-GS pipeline allocates galaxies to the different sized hexabundles and different resolution spectrographs based on a formula that has been extensively modelled to optimise the fraction of each hexabundle that will contain useful data for stellar kinematics and/or emission line physics. The median surface brightness of the Hector-GS galaxies is $r = 22 mag/arcsec^2$ at $1R_e$ and the $90^{th}$ percentile is at $r = 23.65 mag/arcsec^2$. Both Spector and AAOmega will achieve that median at a S/N=20/Å unbinned and the $90^{th}$ percentile at a S/N=5/Å unbinned (higher with binning) in a 4 hour exposure (see plots from the exposure time calculator as presented in the Hector Science document Fig.10] https://hector.datacentral.org.au/uploads/hec-spc-001-science-case-document-v-1-0-signed.pdf). The throughput of the AAOmega instrument and the fibre cable to AAOmega is well characterised from SAMI. The new front end hexabundles will not change the throughput from SAMI. The Spector spectrograph requires a longer fibre cable which entails a slightly higher loss, but was built to optimise for throughput, giving a net similar throughput (which will be compared to the modelled integration time calculator during commissioning).

**Observing strategy:** One of the Hector hexabundles on each of the Spector and AAOmega spectrographs will be used to measure a secondary standard star for both flux and PSF calibration. The remaining 19 hexabundles will be on galaxies. Each field of 19 galaxies will be observed in a 7-point dither pattern (previously optimised for SAMI) using 30 minute exposures plus calibration overheads for arcs and flat exposures. We will observe an average of 2 fields per clear night (slightly more in winter and less in summer). The complete Hector-GS aims to target 15,000 galaxies in 100 nights per year for 6 years (38 galaxies per night, then accounting for weather overheads).

Using 2dF, we plan to acquire redshifts for $\approx 30$ galaxies per square degree ($\sim 100$ 2dF fibres per field, with significant cosmic variance), with an exposure times of $2 \times 10$ minutes per pointing to reach S/N ratio of 10 Å$^{-1}$. Including overheads, we estimate that each field will take 40 minutes, allowing observations of between 10 and 12 fields per night (which we have confirmed to be practical with experienced 2dF observers).

A full observing preparation pipeline exists for Hector, which tiles the fields using a modified Greedy algorithm to maximise tiling for sky coverage, then calculates positions on the field plate accounting for distortions in the optics, and thermal changes. Next the configuration code sets the 3D rotation of the hexabundles for placement while the collision code optimises positioner magnet placement order and then writes out the observing files required for the positioner robot and for observations as well as graphical plots required for astronomers to place the hexabundles on each of the configured magnet pairs [6].

We will use the SAMI data reduction pipeline, modified to handle data from the Spector spectrograph, to process all observations. By using a well-established pipeline we will be able to produce publication-quality data cubes immediately after observations take place, allowing rapid turn-around of the data. We are continuing to optimise the SAMI/Hector pipeline, supported by $\sim$ \$30k (equivalent value) funding from ADACS, resulting in continuous improvements in the (already excellent) data quality, as demonstrated in the recent SAMI DR3 [12].

**A highly qualified team:** The Hector Science team has a wealth of experience with observing on the AAT, data reduction of integral field data, and with the instrumentation. This comes from a strong overlap with the SAMI science team members, and senior team members who have used many instruments on the AAT. The observing process for Hector will be similar to SAMI. New observers will be trained throughout the Hector-GS to ensure the team can provide two observers per Hector observing run.

**Availability of data:** The data is available immediately to team members and will be publicly released over time. We anticipate the first public data release 2 years into the survey once the first 5,000 galaxies are observed and quality controlled. The second data release will be at 10,000 galaxies and the final release at the end of the 15,000 galaxy survey.

## Team Expertise

The Hector Science team has a wealth of experience with observing on the AAT, data reduction of integral field data, and with the instrumentation. This comes from a strong overlap with the SAMI science team members, and senior team members who have used many instruments on the AAT. The observing process for Hector will be similar to SAMI. New observers will be trained throughout the Hector Survey to ensure the team can provide two observers per Hector observing run. More than 30 members of the Hector Science team have previous AAT observing experience.

Table 1. Principal Targets

| Field Name | R.A (°) | Dec (°) | Median $r$-band surface brightness (mag arcsec$^{-2}$ at 1 $r_e$) | $2\sigma$ range of $r$-band surface brightness (mag arcsec$^{-2}$ at 1 $r_e$) | $r$-band magnitude | Exposure Time (minutes) | Instrument | Priority |
|---|---|---|---|---|---|---|---|---|
| G23 | 338.1 – 351.9 | -35 – -30 | 22.0 | 19.7 – 24.5 | – | 240 | Hector | High |
| Cluster A0151 | 17.1092 | -15.4092 | 22.0 | 19.7 – 24.5 | – | 240 | Hector | High |
| Cluster A3158 | 55.7704 | -53.6531 | – | – | $< 17.7$ | 20 | 2dF | Medium |
| Cluster A3266 | 67.7746 | -61.4436 | – | – | $< 17.7$ | 20 | 2dF | Medium |
| Cluster A3667 | 303.0917 | -56.8152 | – | – | $< 17.7$ | 20 | 2dF | Medium |
| Cluster A3716 | 312.8600 | -52.7070 | – | – | $< 17.7$ | 20 | 2dF | Medium |
| WAVES South Field 1 | 9 – 21 | -28.5 – -33.5 | – | – | $< 17.7$ | 20 | 2dF | High |
| WAVES South Field 2 | 39 – 51 | -28.5 – -33.5 | – | – | $< 17.7$ | 20 | 2dF | High |

Table 2. Backup Targets. Our poor-weather backup targets will be brighter objects from the same fields.

| Field Name | R.A (°) | Dec (°) | Median $r$-band surface brightness (mag arcsec$^{-2}$ at 1 $r_e$) | $2\sigma$ range of $r$-band surface brightness (mag arcsec$^{-2}$ at 1 $r_e$) | $r$-band magnitude | Exposure Time (minutes) | Instrument | Priority |
|---|---|---|---|---|---|---|---|---|
| G23 | 338.1 – 351.9 | -35 – -30 | 22.0 | 19.7 – 22 | – | 240 | Hector | High |
| Cluster A0151 | 17.1092 | -15.4092 | 22.0 | 19.7 – 22 | – | 240 | Hector | High |
| Cluster A3158 | 55.7704 | -53.6531 | – | – | $< 17.7$ | 20 | 2dF | Medium |
| Cluster A3266 | 67.7746 | -61.4436 | – | – | $< 17.7$ | 20 | 2dF | Medium |
| Cluster A3667 | 303.0917 | -56.8152 | – | – | $< 17.7$ | 20 | 2dF | Medium |
| Cluster A3716 | 312.8600 | -52.7070 | – | – | $< 17.7$ | 20 | 2dF | Medium |
| WAVES South Field 1 | 9 – 21 | -28.5 – -33.5 | – | – | $< 17.7$ | 20 | 2dF | High |
| WAVES South Field 2 | 39 – 51 | -28.5 – -33.5 | – | – | $< 17.7$ | 20 | 2dF | High |