Science and Technology Facilities Council
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PATT2
Version 02/2013

APPLICATION FOR TELESCOPE TIME (OPTICAL AND INFRARED)

1 TELESCOPE *(AAT, UKST, WHT, INT or UKIRT)*	WHT	Reference:	Date stamp:
2 SEMESTER	2020B	3 SCIENTIFIC CATEGORY	4

4 COORDINATED PATT PROPOSALS: *AAT:*☐ *UKST:*☐ *WHT:*☐ *INT:*☐ *UKIRT:*☐ *JCMT:*☐ *GEMINI:*☐ *LT:*☐ *MERLIN:*☐

5 PRINCIPAL APPLICANT

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Is the applicant a possible observer? Yes

6 COLLABORATORS

Name:	Institute:	Observer?
Dr Rebecca Smethurst	University of Oxford	Yes
Tobias Géron	University of Oxford	Yes
Dr Brooke Simmons	Lancaster University	Yes
Izzy Garland, David O'Ryan	Lancaster University	Yes

7 SHORT TITLE OF PROPOSAL *(maximum 12 words)*

Are strong and weak bars different?

8 SUMMARY OF PROPOSED OBSERVATIONS

Recent theoretical and observational work constraining the influence of mergers on galaxy evolution and growth has focused attention on the secular processes which must shape the local galaxy population, including the presence of a bar. In galaxies with strong and dominant bars, the bar can either trigger starbursts or dynamically heat gas, preventing star formation, in either case triggering a quench. Yet such strongly barred galaxies represent a minority of the disk galaxy population. We use a newly assembled sample to determine for the first time the effect of even a weak bar feature on the galaxy, using spectra from ISIS on the WHT to measure gas inflow in samples of weakly barred, strongly barred and control systems. These observations represent an important step in understanding the contribution of barred morphological quenching to the bulk of the disk galaxy population.

9 FOCAL STATION, INSTRUMENT AND DETECTOR

Focal station:	Instrument:	Detector(s):	Gratings/Filters:
f/11	ISIS	EEV12, RED+	R300B, R316R

10 OBSERVING TIME REQUESTED THIS SEMESTER

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Time requested this semester	3			Nights
Minimum useful allocation this semester	3			

UKIRT applicants requiring dark time must justify this in section 18

11 COMPLETE THIS SECTION ONLY IF THIS IS A LONG TERM PROPOSAL

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Total time requested				

12 SCHEDULING INFORMATION

Preferred dates:	January
Impossible dates: *Give justification for impossible dates*	
If observations are to be simultaneous with other telescopes or satellites, give details:	
Any other scheduling constraints: *Include likely clashes with other time applications, constraints on lunar position or quarter, instrument preparation requirements, etc*	

13 SERVICE OBSERVING

yes: [ ] no: [ ] maybe: [x]

14 SUPPORT ASTRONOMER REQUESTED AT TELESCOPE

every night: [ ] no: [ ] first night only: [x]

15 LIST OF PRINCIPAL TARGETS

Object(s):	RA(h,m):	Dec(degs):	Mag(type):	Colour:	Exp. Time:
J015911.34+000635.1	01:59:11.34	+00:06:35.1	20.71	-	26.7
J011242.10+010839.2	01:12:42.10	+01:08:39.2	20.88	-	33.3
J102153.20+001743.3	10:21:53.20	+00:17:43.3	20.26	-	15.0
J142049.60+052627.5	14:20:49.60	+05:26:27.5	20.44	-	18.3
J092000.86+192200.2	09:20:00.86	+19:22:00.2	21.71	-	116.7
J135256.55+024851.4	13:52:56.55	+02:48:51.4	19.59	-	6.7
J022809.70+004756.6	02:28:09.70	+00:47:56.6	19.40	-	5.8
J133524.55+012438.1	13:35:24.55	+01:24:38.1	19.84	-	10.0

and 22 other similar targets

16 LIST ALL SIMILAR/SUPPORTING APPLICATIONS TO ANY PATT OR OTHER TIME ASSIGNMENT COMMITTEE

You must include a brief description of any other applications whose targets or science goals are similar to those requested here

Telescope/satellite:	Title/Description of programme:

Case not to exceed this A4 page. Figures and/or references can be included on page 4a

Understanding the role that internal processes play in galaxy evolution is a key goal of modern astrophysics. An increasing body of evidence shows that galaxy evolution and growth is mainly driven by secular, or non-merger driven, processes ; Kaviraj et al. (2012)[1], for example, have shown that only 27% of star formation is triggered by major or minor mergers. Recent work in cosmological simulations (e.g. Martin et al. 2018[2], McAlpine et al. 2020[3]), following observational work by Simmons, Smethurst & Lintott (2017)[4], also reveals the importance of secular processes.

It is therefore important to identify the dominant mechanisms responsible for galaxy growth and the quenching (or cessation) of star formation. One candidate process is the funneling of gas from the outskirts of a galaxy by a galactic-scale bar (Athanassoula 1992[5]); bars are thought to remove gas needed for star formation in the outer regions and deposit it in the centre, where it either triggers a starburst or is too dynamically hot to be used for future star formation (Zurita et al. 2004[6], Sheth et al. 2005[7], Jogee et al. 2005[8]), in either case creating a quench (see Figure 2).

However, this process has been observed only in galaxies with strong bars, where the bar is the dominant feature. Yet a large range of bar strengths are seen across the galaxy population with a broad distribution of bar lengths, widths and relative sizes, and systems with strong bars are in the minority (Masters et al. 2011[9]). While strongly barred galaxies are preferentially located on the red sequence - an indication that the presence of the bar may be effective in quenching, galaxies with weaker bars are evenly distributed across the colour-magnitude diagram (see Figure 2). **This suggests that weak and strong bars may not affect a galaxy in the same way**. Most previous studies have focussed their efforts on the strong bar population (Rosas-Guevara et al. 2020[10], Newnham et al. 2020[11], Khoperskov et al. 2018[12]) which are easier to detect since they are brighter and constitute the main feature of the galaxy; or don't make the distinction between weak and strong bars (Cheung et al. 2013[13], Masters et al. 2011[9]). The absence - until now - of a large sample of weak bars has prevented equivalent observations for weakly barred systems.

Cuomo et al. 2019[14] measured the bar pattern speed in a small sample of 16 weakly barred spirals, finding no significant differences between strongly and weakly barred systems, which suggests that any differences must be due to the way the bar interacts with the gas. In this project we propose to observe a mass-matched sample (see Figure 1) of strong and weak bars along with a control sample of unbarred galaxies. These galaxies are selected from a new Galaxy Zoo sample which has, for the first time, distinguished between strong and weak bars. We will use the ISIS spectrograph on the WHT to obtain spectra along and perpendicular to the bar for each target (unbarred galaxies will have the slit aligned along the major and minor axes). The flexibility provided by the choice of gratings makes ISIS the ideal instrument to achieve our science goals. Whilst these galaxies would be interesting targets for an IFU survey, no such survey has yet included a sufficiently large number of these systems for the study we propose here. Instead, observations with ISIS will allow us to target a mass-matched sample of strong and weak bars across the colour-magnitude diagram and supplement the existing small number samples from IFU surveys such as MaNGA (Bundy et al. 2015[15]).

Resolving the emission lines in each target across a large range of wavelengths with ISIS will allow us to determine the gas kinematics along and perpendicular to the bar. We will test whether there is a significant inflow of gas along both strong and weak bars, comparing the measurements to those taken outside the bar (and compared to the control sample of unbarred galaxies). We aim to definitely answer the question; do weak bars drive gas to the centre of a galaxy at the same or different rates to strong bars, and are they therefore capable of quenching?

The simultaneous observation of both the blue and red side of the spectrum with ISIS will also allow us to determine the star formation rates within and outside strong and weak bars using $H\alpha$ on the red side, and $D_n4000\text{Å}$ and [OIII] on the blue side (Spindler et al. 2018[16]). These resolved star formation rates will be crucial to determining whether both weak and strong bar structures are responsible for any decrease in the star formation rate in these galaxies. This will allow us to determine if strong and weak bars are separate phenomenon.

We will publish two papers as a result of these observations: (1) determining the gas kinematics to determine whether their bars allow gas to flow towards their centres and (2) constraining the star formation rates inside and outside of the bar to determine whether either strong or weak bars are directly responsible for quenching galaxies. With this work we aim to characterise the differing or similar effects of weak and strong bars to determine their overall contribution to galaxy evolution.

17 SCIENTIFIC JUSTIFICATION

Continuation page for AAT, WHT and UKIRT proposals for 8 or more nights, and for all long-term and coordinated proposals

18 TECHNICAL INFORMATION (I)

Give details of the technical feasibility of the proposal (S/N,etc) AND any non-standard technical requirements

The parent sample from which our galaxies are drawn is made up of all SDSS galaxies for which reliable bar classifications were made with Galaxy Zoo 2 (Willett et al. 2013[17]). We volume limited our sample with a redshift range, $0.01 < z < 0.05$ and a magnitude limit $M_r < -19.73$. From our parent sample, we mass-matched 10 galaxies with strong bars, 10 with weak bars and 10 without bars, for a total of 30 galaxies. In every bar category, half are in the blue cloud and half in the red sequence (see Figure 2). All our targets also overlap with the ALFALFA footprint (Giovanelli et al. 2005[18]) in order to give global gas masses. We chose targets which were not in the MaNGA target list (Bundy et al. 2015[15]), CALIFA (Sánchez et al. 2012[19]) and SAMI (Scott et al. 2005[20]), so as to avoid unnecessary duplicate observations. Such broad IFU studies typically aim to observe a general sample of the galaxy population and thus have too few galaxies that fit our requirements to allow for a statistically robust study of the effect of strong and weak bars that we propose.

The ISIS spectrograph on the WHT is ideal for observing this sample as it allows the simultaneous observation of the red and blue sides of the spectrum in combination with the flexibility of the gratings available. This allows us to optimise the wavelength range targeted against the spectral resolution in order to maximise the science output. We therefore propose to target the $H\alpha$ emission line in each of our sources with the R316R grating on the RED+ detector, with simultaneous observations of the D_n4000Å break-$H\beta$-[OIII] region ($5067 < \lambda_{emit}$[Å]< 5245) using the R300B on the EEV12 detector. Probing these regions of the spectrum specifically will allow us to observe a maximum number of emission lines to derive precise gas kinematics whilst also allowing for an accurate determination of the resolved star formation rate in and outside the bar (Spindler et al. 2018[16]).

In order to derive an accurate measure of the gas inflow rates in our targets, we need to be able to determine the gas kinematics. We will utilise the tried and tested PPXF spectral fitting code (Cappellari & Emsellem 2004[21]) to derive the velocity of the gas along the bar for each of our targets. To do this we require a high signal-to-noise ratio (SNR) to ensure that each of the emission lines in the sample are well resolved. To achieve a $SNR = 10$ for each of our targets we calculated an exposure time given the quantum efficiency of the detectors at the redshifted wavelength of $H\alpha$ ($6641 < \lambda_{emit}$[Å]< 6874) and assuming negligible sky background on dark sky nights with respect to the read noise of the EEV12 and RED+ detectors. Given these requirements the total on source time is 18.1 hours, assuming a seeing of 1" and optimal airmass conditions. The minimum (maximum) exposure time for a single source is ~ 4 (142) minutes.

Using this information combined with the overhead estimates from the ISIS Total Observing Time Estimator and assuming an average weather downtime of 34% in January, we calculate that we can observe all 30 targets in 3 nights of dark skies in January of the 2020 semester.

[1] Kaviraj et al. 2013, MNRAS, 429, 40
[2] Martin et al. 2018, MNRAS, 476, 2801
[3] McAlpine et al. 2020, arXiv 2002.00959
[4] Simmons, Smethurst & Lintott, 2017, MNRAS, 470, 1559
[5] Athanassoula 1992, MNRAS, 259
[6] Zurita et al. 2004, A&A, 413
[7] Sheth et al. 2005, ApJ, 632, 1
[8] Jogee et al. 2005, ApJ, 630, 2
[9] Masters et al. 2011, MNRAS 411, 3
[10] Rosas-Guevara et al. 2020, MNRAS, 491, 2
[11] Newnham et al. 2020, MNRAS, 492, 4
[12] Khoperskov et al. 2018 A&A 609, A60
[13] Cheung et al. 2013, ApJ 779, 2
[14] Cuomo et al. 2019, A&A, 632, A51
[15] Bundy et al. 2015, ApJ, 798, 7
[16] Spindler et al. 2018, MNRAS, 476, 1
[17] Willett et al. 2013, MNRAS, 435, 3
[18] Giovanelli et al. 2005 AJ 130, 6
[19] Sánchez et al. 2012 A&A 538, A8
[20] Scott et al. 2005 MNRAS 481, 2
[21] Cappellari & Emsellem, 2004, PASP, 116, 138

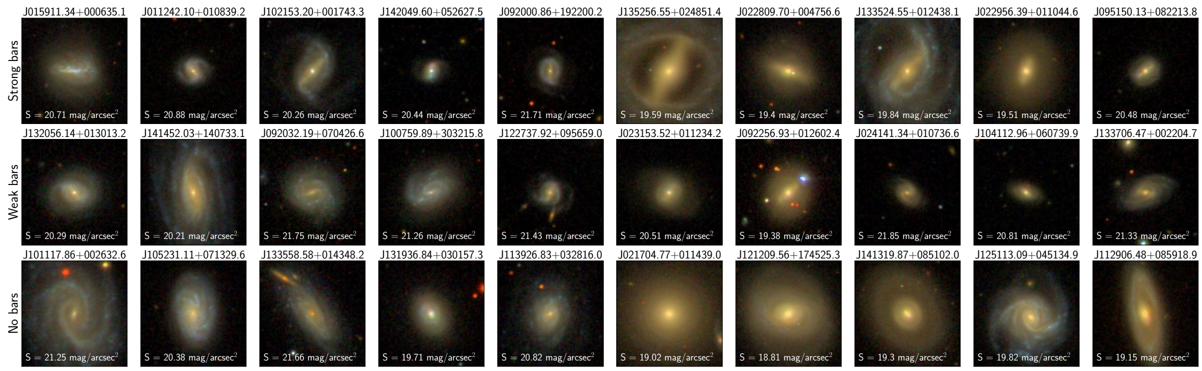

Figure 1: Mosaic of SDSS *ugriz* postage stamps of targets in this sample ($0.01 < z < 0.05$). The sample is split into strong bars (top), weak bars (middle) and no bars (bottom; our control sample) which are mass-matched along each column. The surface brightness of each source is also noted. The 5 leftmost columns are galaxies in the blue cloud and the 5 rightmost columns are all galaxies in the red sequence (see Figure 2). Each image is 63 arcseconds across.

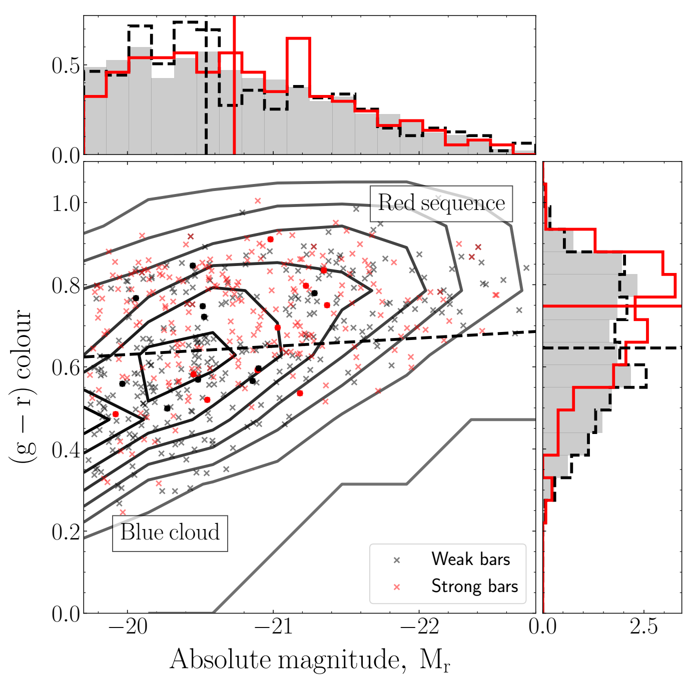

Figure 2: Colour magnitude diagram showing the locations of strong (red crosses and histogram) and weak (black crosses and histogram) bars in the parent sample. Circles show targets in this proposal. We also show the overarching distribution of galaxies in SDSS across this plane (black contours and grey histogram). We see a significant difference between the distribution of colours in strong and weak bars; with strong bars found preferentially on the red sequence (~70% of total strong bar population) and weak bars evenly distributed (6.7σ and 0.27σ difference from the overarching SDSS galaxy population for strong and weak bars, respectively). We therefore aim to test the hypothesis that strong bars cause the quenching of star formation, driving disc galaxies from the blue cloud to the red sequence, whereas weak bars do not.

19 SUMMARY OF BACKUP PROGRAMME FOR POOR OBSERVING CONDITIONS

If instrumentation or setup differs from main programme, give full details

In the case of poor seeing we shall limit the number of sources targeted and increase exposure times in order to still achieve optimal signal-to-noise ratios for a selection of our targets (initally those with shorter calcualted exposure times). This will still allow the kinematics and star formation rates to be determined but in a reduced sample size.

20 RELATED PATT APPLICATIONS OVER THE LAST FOUR SEMESTERS *(including unsuccesful applications)*

PATT reference:	Award:	Clear nights:	Comments:

21 PUBLICATIONS BASED ON PATT TIME PUBLISHED DURING THE LAST FOUR SEMESTERS *(maximum 6)*

22 EXPERIENCE OF INTENDED OBSERVERS WHO HAVE NOT PREVIOUSLY USED THIS TELESCOPE

CL, RS and BS have all had experience observing with IDS on the INT. BS and RS have experience on the Shane 3-m at the Lick Observatory with both spectra and imaging. CL, RS and have experience on the CSO, Mauna Kea (BS has remote experience of this telescope).

23 COMPLETE IF THE OBSERVATIONS ARE PRIMARILY FOR A STUDENT RESEARCH TRAINING PROGRAMME

Name of student:	Tobias Géron
Project title:	Quenching Galaxies with Galaxy Zoo

24 COMPLETE IF THE OBSERVATIONS ARE ASSOCIATED WITH A CURRENT STFC RESEARCH GRANT

Name of principal investigator:	
Grant title:	
Grant number:	

25 NON-STANDARD TRAVEL AND SUBSISTENCE REQUIREMENTS *(UK observers only)*

Justify requests for travel and subsistence for more than one person:

Details of any other expenditure (eg freight, remote observing):