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PATT2
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APPLICATION FOR TELESCOPE TIME (OPTICAL AND INFRARED)

1 TELESCOPE *(AAT, UKST, WHT, INT or UKIRT)*	INT	Reference:	Date stamp:
2 SEMESTER	2023B	3 SCIENTIFIC CATEGORY	4

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

5 PRINCIPAL APPLICANT

Surname: Title: First name:
Post held:
Address:

Telephone: Fax:
E-mail: Is the applicant a possible observer?

6 COLLABORATORS

Name:	Institute:	Observer?
Tobias Géron	University of Oxford	Yes
Dr Rebecca Smethurst	University of Oxford	Yes
Dr Brooke Simmons	Lancaster University	Yes
Prof Chris Lintott	University of Oxford	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 IDS on the INT 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:
Cassegrain	IDS	EEV10	R300V

10 OBSERVING TIME REQUESTED THIS SEMESTER

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Time requested this semester	5			Nights
Minimum useful allocation this semester	5			

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:	(late) Sep, (early) Oct, Jan
Impossible dates:	Aug, Nov, Dec
Give justification for impossible dates	Targets have wrong RAs
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: [ ]

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:
NB_1	00 58 48.8506	00.587277	13.51	0.54	11
NB_2	00 10 39.3502	-0.052891	14.32	0.53	12
WB_1	01 24 55.2247	00.211588	14.8	0.49	64
WB_2	00 57 41.8827	15.06805	14.89	0.54	110
SB_1	01 36 00.1502	00.663477	13.19	0.69	19
SB_2	01 07 14.2381	13.955141	13.76	0.69	52
SB_3	00 35 14.5384	00.695974	14.74	0.59	65

and 7 other similar targets. Magnitudes are r-band magnitudes from the Legacy survey. Colour is the g-r colour obtained from Petrosian magnitudes from SDSS. Exposure time is in minutes.

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 causing a quench.

However, this process has only been observed in galaxies with strong bars, where the bar is the dominant feature. Most previous studies have focussed their efforts on the strong bar population (Rosas-Guevara et al. 2020[9], Newnham et al. 2020[10], Khoperskov et al. 2018[11]) which are easier to detect since they are brighter and constitute the main feature of the galaxy. 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[12]). While strong bars appear more frequently in quiescent galaxies - an indication that the presence of the bar may be effective in quenching - galaxies with weaker bars are evenly distributed between star forming and quiescent galaxies. **This suggests that weak and strong bars may not affect a galaxy in the same way** (Géron et al. 2021[13]). The absence - until now - of a large sample of weak bars has prevented equivalent observations for weakly barred systems.

In this project we propose to observe a 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, called Galaxy Zoo DESI, which distinguishes between strong and weak bars (Walmsley et al. 2023[14]). We propose to use the IDS spectrograph on the INT to obtain spectra parallel and perpendicular to the bar (and, time permitting, halfway in between for each target). The flexibility provided by the choice of gratings makes IDS the ideal instrument to achieve our science goals.

The results of Géron et al. 2023[15] show that strong and weak bars have significantly different pattern speeds, which hints that there are differences in the gas kinematics of strong and weak bars as well. Resolving the emission lines in each target across a large range of wavelengths with IDS 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?

Choosing a grating on the IDS which balances the spectral resolution while targetting a large wavelength range will also allow us to determine the star formation rates within and outside strong and weak bars using $H\alpha$, $D_{\mathrm{n}}4000$ and [OIII] (Spindler et al. 2018[16]). These resolved star formation rates will be crucial to determining whether both weak and strong bars 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 submitted a similar proposal for the 2022B semester and we were awarded 5 dark nights. Unfortunately, due to storm Hermine, we were only able to observe one strongly barred target. Nevertheless, for this one target, we found interesting differences in the amount of $H\alpha$ between the parallel and perpendicular slit, with significantly more $H\alpha$ flux found in the parallel slit, as shown in Figure 2. This proof-of-concept shows the viability of this study and indicates that it is worthwhile to observe the entire sample.

We will publish two papers as a result of these observations: (1) measuring 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

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 galaxies with reliable bar classifications from GZ DESI (Walmsley et al. 2023[14]). We volume limit our sample with a redshift range, $0.01 < z < 0.05$ and a magnitude limit $M_r < -18.96$. From our parent sample, we matched 7 galaxies with strong bars, 7 with weak bars and 7 without bars, for a total of 21 galaxies. This sample size and setup allows for a meaningful study of all bar types and will help us to disentangle any potential differences between weak and strong bars. In case of bad weather we would focus our efforts on the brightest targets and reduce the number of slit angles, which will allow us to still gain valuable insight into the effect of the bar on the gas kinematics.

We chose targets which were not in the MaNGA target list (Bundy et al. 2015[17]), CALIFA (Sánchez et al. 2012[18]) or SAMI (Scott et al. 2005[19]), to avoid unnecessary duplicate observations.

The IDS spectrograph on the INT is ideal for observing this sample due to 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 R300V grating on the EEV10 detector, which still has a large enough wavelength range to also capture the D_n4000Å break-$H\beta$-[OIII] region ($5067 <$ [OIII]λ_{emit}[Å]< 5245) with high efficiency. Targeting these regions of the spectrum specifically will allow us to observe a maximum number of emission lines with high resolution 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]).

The R300V grating has a dispersion of 1.87 Å/pix. For the wavelength range we are interested in (~4929 - 6917 Å), this translates to a resolution of ~81 - 114 km/s. From the experience of the authors, the centroid of an emission line can be detected to ~1/10th of a pixel. Given the dispersion of the R300V grating and a targetted SNR of ~10, we expect to be able to characterise the uncertainty on the gas velocities up to ~8 - 11 km/s. Simulations have shown that gas inflows due to bars can reach velocities of the order of ~100 km/s (Athanassoula, E. 1992[5], Kim et al. 2012[20]), which suggests that we will be able to detect them, or at the very least constrain their upper limits. We have also confirmed that all our targets have been detected by the ALFALFA Extragalactic HI Source Catalog (Giovanelli et al. 2005[21], Haynes et al. 2018[22]) in order to ensure presence of HI gas.

We want to measure the gas flow along and perpendicular to the bar and compare it for weak and strong bars. In order to do this, we propose to align the slit parallel and perpendicular to the bar (unbarred galaxies will have the slit aligned along the major and minor axes). Additionally, time permitting, to more easily isolate non-axisymmetric motion, we are planning to align the slit 45° away from the bar (or major axis for unbarred galaxies) as well. 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 penalized pixel-fitting method (PPXF) spectral fitting code (Cappellari & Emsellem 2004[23]) 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. We've used the Exposure Time Calculator SIGNAL using surface brightness measurements based on DESI r-band magnitudes to calculate appropriate exposure times to achieve a SNR of 10. However, we note that our science goals will still be possible if observations are limited to lower SNR (e.g. SNR > 3) due to seeing limitations or time constrains. While using the ETC, we've assumed negligible sky background on dark sky nights with respect to the read noise and taken into account the quantum efficiency of the detector at the redshifted wavelength of $H\alpha$ ($6641 < \lambda_{emit}$[Å]< 6874). Given these requirements the total on source time is 26.5 hours, assuming a seeing of 1" and optimal airmass conditions. The minimum (maximum) exposure time for a single source is ~ 12 (145) minutes.

Using this information combined with the overhead estimates from the IDS Total Observing Time Estimator, we calculate that we can observe all 21 targets in 4.3 (rounded up to 5) nights of dark skies in October 2023 of the 2023B semester.

We also applied for and were awarded four nights of observing time for this project during the 2020B, 2021B and 2022B semesters, but due to extreme weather conditions and the volcano erupting we were not able to observe much in any semester.

Finally, we want to note that the targets presented here are valid if we receive time in September/October. We can also construct a similar sample in case we receive telescope time in January.

References and Figures

[1] Kaviraj et al. 2013, MNRAS, 429, L40
[2] Martin et al. 2018, MNRAS, 476, 2801
[3] McAlpine et al. 2020, MNRAS, 494, 5713
[4] Simmons, Smethurst & Lintott, 2017, MNRAS, 470, 1559
[5] Athanassoula 1992, MNRAS, 259, 345
[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] Rosas-Guevara et al. 2020, MNRAS, 491, 2547
[10] Newnham et al. 2020, MNRAS, 492, 4697
[11] Khoperskov et al. 2018 A&A 609, A60
[12] Masters et al. 2011, MNRAS 411, 2026
[13] Géron et al. 2021, MNRAS, 507, 4389
[14] Walmsley et al. 2023, in preparation
[15] Géron et al. 2023, accepted for publication in MNRAS
[16] Spindler et al. 2018, MNRAS, 476, 580
[17] Bundy et al. 2015, ApJ, 798, 7
[18] Sánchez et al. 2012, A&A 538, A8
[19] Scott et al. 2005, MNRAS, 481, 2
[20] Kim et al. 2021, ApJ, 747, 1
[21] Giovanelli et al. 2005, AJ 130, 6
[22] Haynes et al. 2018, ApJ, 861, 1
[23] Cappellari & Emsellem, 2004, PASP, 116, 138

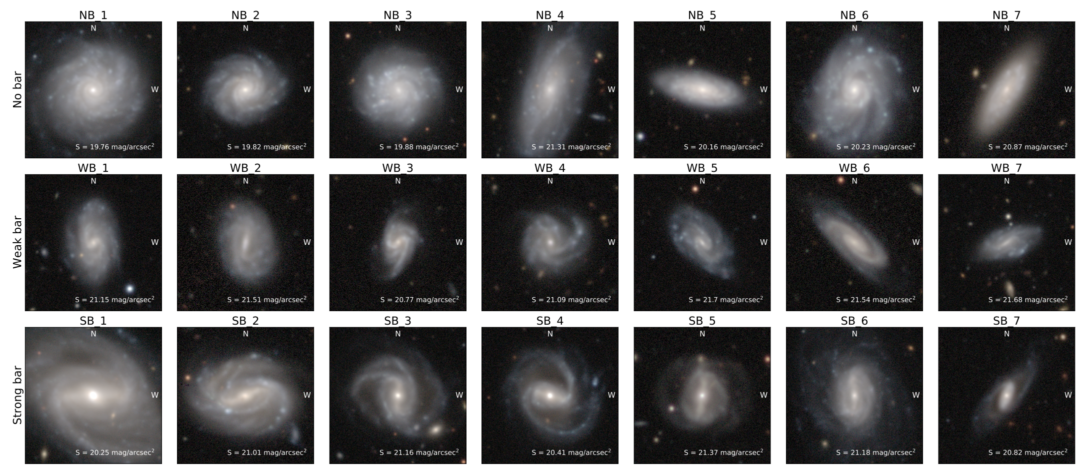

Figure 1: Mosaic of postage stamps obtained from the DESI Legacy survey of targets in this sample ($0.01 < z < 0.05$). The sample is split into no bars (top; our control sample), weak bars (middle) and strong bars (bottom), which are mass-matched along each column. The surface brightness of each source is also noted. Each image is 64 arcseconds across.

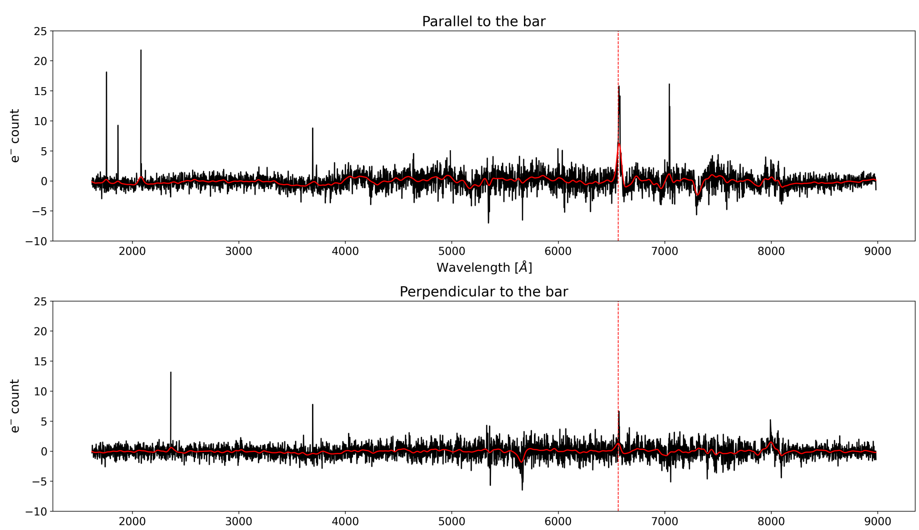

Figure 2: The spectra of the one target (SB_5) that was observed during the 2022B semester. The spectra with the slit placed parallel to the bar is shown in the top panel, while the spectra obtained with the slit placed perpendicular to the bar is shown in the bottom panel. The dashed vertical lines represent where it is expected to see $H\alpha$ emission.

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 will limit the number of sources targeted, decrease the number is slit angles and increase exposure times in order to still achieve optimal signal-to-noise ratios for a selection of our targets (initially those with shorter calculated 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:
I/2020B/09	4 nights	0 clear nights	We could not observe any of our targets due to extremely bad weather caused by storm Filomena.
I/2021B/04	5 nights	0 clear nights	We could not observe any of our targets to due the volcanic eruption on the island.
I/2022B/8	5 nights	0.5 clear night	We could only observe one of our targets due to the extremely bad weather caused by storm Hermine.

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, BS, RS, TG and the PI have had experience observing with IDS on the INT. RS and BS have experience on the Shane 3-m at the Lick Observatory with both spectra and imaging. CL and RS 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:	
Project title:	

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):