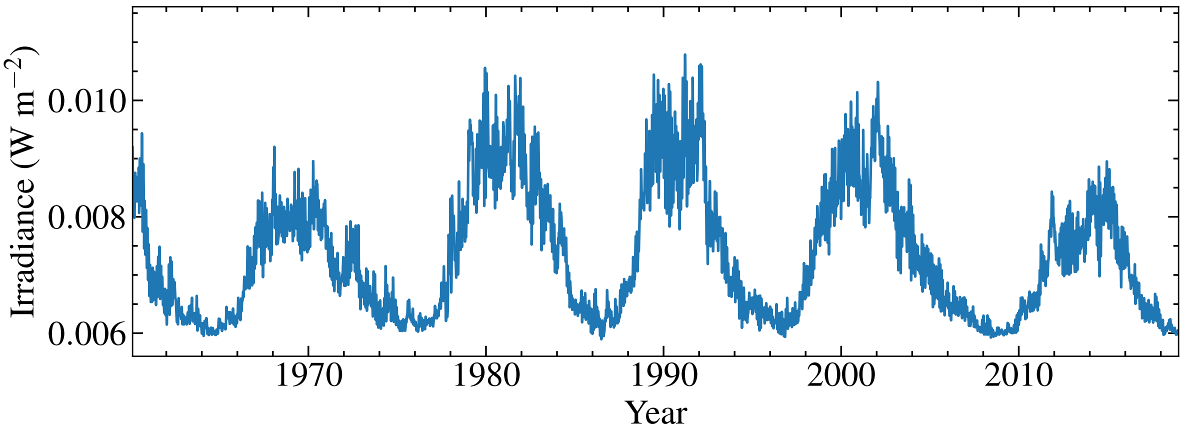

Figure 1: Lyman α irradiance from the Sun since the beginning of the Space Age, which varies with the $\approx$11 year Solar cycle (Machol et al., 2019). We have detected the first evidence for similar Lyman α variation linked with a stellar cycle at an M dwarf. Two new observations, one as soon as possible and another one-two month later, will allow us to confirm the period of the cycle.

■ Rationale for DD Time

The most recent spectroscopic observations of GJ 1132 that anchor the potential orbital variability were acquired after the last proposal deadline. We request DD time here because the epoch for the best discrimination between the likely periods extends to May of this year, requiring time-sensitive observations before the next proposal cycle.

■ Science Justification

The Solar Cycle, a roughly 11-year fluctuation in stellar activity indicators such as Sun spot number, flare rate and emission line strength, is a well-established behaviour of the Sun. Similar long-term (multi-year) cycles have been detected at other stars via decades-long measurements of Ca II H&K emission line strength, which is a strong tracer of the Solar cycle on the Sun. However, these stars have been for the most part G- and K-type stars with similar masses to the Sun, along with a number of early-type M dwarfs (Suárez Mascareño et al., 2018). Pushing down to lower-mass M dwarfs is challenging as their Ca II H&K lines tend to be too faint to reliably measure variation, requiring alternative observational signatures to be used.

Searching for stellar cycles on low-mass stars is important, both for a complete understanding of stellar astrophysics, as M dwarfs represent the majority of all stars and probe changes in magnetic field behavior across the fully convective limit, and also because M dwarfs are the most promising targets for exoplanet research in the next decade. The small size of M dwarfs makes finding rocky plants around them relativity easy compared with larger stars. In particular they are prime targets for discovering planets with Earth-like equilibrium temperatures, as the orbital periods of such planets are relatively short so less observing time is required to confirm their presence. However, as these temperate planets are therefore much closer to their stars, the potential effects from stellar activity can be considerably stronger than at the Earth. Understanding stellar activity is a core requirement for assessing the surface conditions on those planets, as it has strong effects on, for example, the density and chemistry of planetary atmospheres and the surface radiation conditions (Airapetian et al., 2019).

Along with the aforementioned Ca II H&K lines, previous measurements of stellar cycles on M dwarfs have tracked changes in apparent rotation rates caused by star spots appearing at different latitudes on the differentially-rotating star over the course of the cycle. Around 30 stars have tentatively identified cycle periods, mostly measured from photometric data obtained with the *Kepler* spacecraft (Küker et al., 2019, and references therein). The periods fall into two populations, with stars with short (~ 10 day) average rotation periods having ≈ 500 day cycles, and more slowly-rotating stars having cycles of roughly 1000 days duration (Vida et al., 2014). The most extensively studied stellar cycle of an M dwarf is that of the closest, Proxima Centauri, for which a seven year cycle was reported by Wargelin et al. (2017) based on changes in V-band magnitude combined with repeated *Swift* ultraviolet and x-ray observations.

Here we present evidence for the detection of a stellar cycle by a new technique and propose a small investment of *HST* time to confirm it. One of the best established tracers of the Solar cycle is emission from the H I 1215 Å Lyman α line (Machol et al., 2019). Figure 1 shows the record of the Solar Lyman α strength over the past few decades, clearly showing the 11-year cycle. As the strongest ultraviolet line, Lyman α is a key contributor to the changing Solar forcing of the Earth's atmosphere over the Solar cycle. For M dwarfs the effects of Lyman α emission may be more profound, as planets with the same temperature as the Earth are much closer to their stars, experiencing stronger ultraviolet fluxes; Lyman α also dominates the far-ultraviolet emission in M dwarfs and is the key driver of ultraviolet photochemistry in exoplanet atmospheres (France et al., 2016).

We have detected evidence for long-term variation in Lyman α strength in the planet-hosting M4 dwarf GJ 1132. Berta-Thompson et al. (2015) discovered a 1.2 Earth-radius planet in a 1.6 day orbit around this star, close enough that evidence for an escaping hydrogen exosphere might be detected by observing the Lyman α line during planetary transits. GJ 1132 has therefore been observed at five different epochs using the STIS G140M grating: Twice in 2016 to establish the detectability of the Lyman α line, then twice again in 2017 in an extensive search for a transiting exosphere, which resulted in a non-detection (Waalkes et al., 2019), and finally in 2019 as part of the Mega-MUSCLES Treasury survey. When we extracted each of these datasets in a consistent manner, we found that the strength of the Lyman α line has significantly varied over time. Figure 2 shows example spectra from each of the five epochs that clearly demonstrate the changes in line flux over a range of around a factor two. This is even more remarkable given that most of the line is obscured by a combination of geocoronal emission and interstellar absorption, leaving only the red line

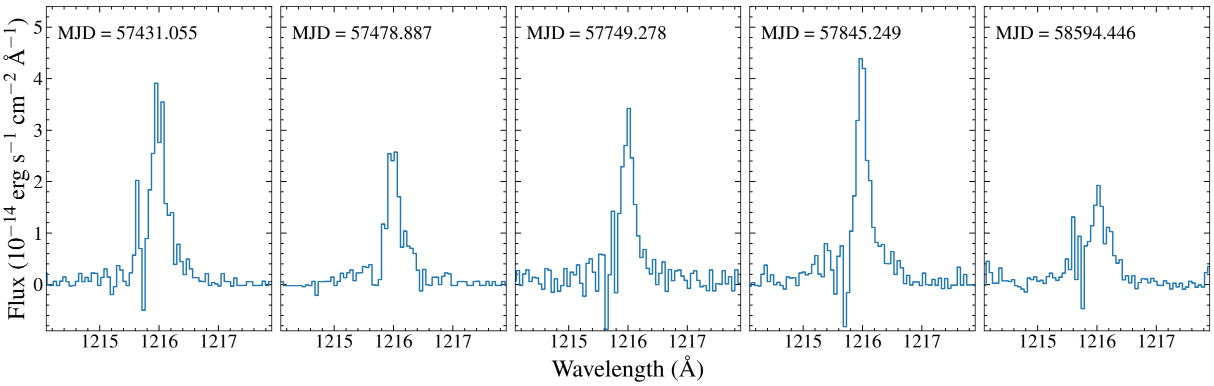

Figure 2: Example STIS G140M spectra of the Lyman α line at GJ 1132, which is clearly varying over time.

wing to exhibit this dramatic variability.

Intriguingly, the Lyman α variability shows signs of being periodic. Computing a Lomb-Scargle periodogram of the integrated Lyman α fluxes (Figure 3) reveals 3 peaks, which were used to fit sine functions to the data to find candidate periods of ≈ 441, 524 and 973 days. The last ~ 1000 d period is almost certainly either a harmonic of one of the first ~ 500 day periods, or vice versa. The existing data better explore the range of flux values predicted by the shorter periods, but the longer period is more consistent with the photometric measurements that predict that a star with the rotation period of GJ 1132 ($P_{\rm rot} \approx 125$ d) should have a stellar cycle with a period of roughly 1000 days. Therefore, the existing data are insufficient to distinguish between the candidate periods, or indeed if the Lyman α flux is periodic at all. Alternatively, the modulation could be driven by rotation. There is a peak at 137 days, similar to the existing rotation period measurement. Conformation that the Lyman α strength varies strongly with rotation would be an equally compelling result, with implications for the ongoing searches for escaping planetary exospheres via measurements of Lyman α transits (e.g. Bourrier et al., 2017).

There is, however, a strategy for immediate confirmation. By coincidence, the predictions made for the Lyman α flux by each of the four candidate periods are easily distinguishable at the present epoch. Two new STIS/G140M observations before the end of May 2020 will allow us to confirm which of the signals, if any, is correct.

If confirmed, this would be the first detection of either a stellar cycle or rotation via changes in Lyman α flux for any M dwarf, or indeed at any star at all apart from the Sun. A successful demonstration of this technique would provide a new method to measure the stellar cycles of M dwarfs, adding to the small sample size of cycles measured via photometric methods. It may in fact be the only usable technique for many M dwarfs: Changes in rotation rates are too faint to be detected in long-term ground-based photometric surveys (and the *TESS* time on target is far too short), and the Ca II H&K lines are too weak to reliably measure variation (Figure 4). Many M dwarfs already have multiple epochs of Lyman α

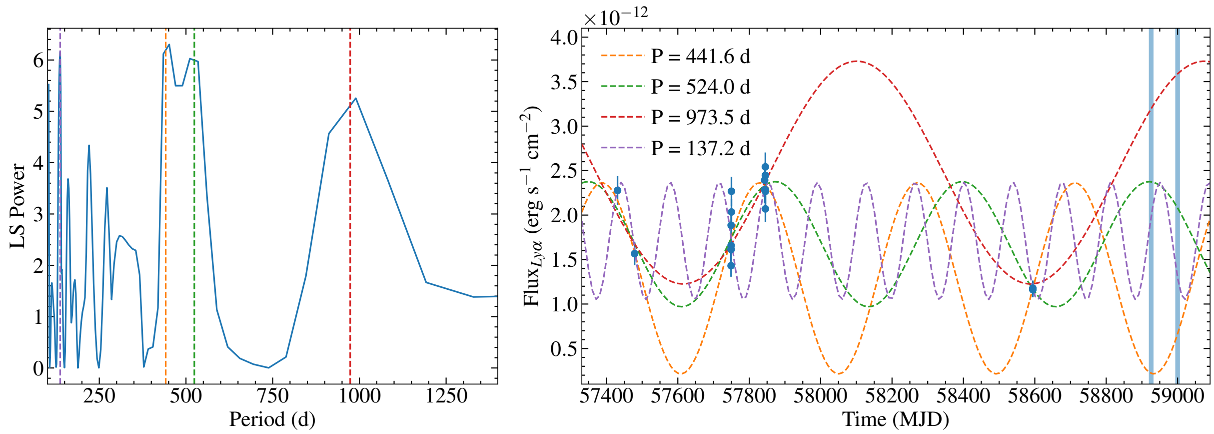

Figure 3: Left: Lomb-Scargle periodogram of the Lyman α flux of GJ 1132. Strong peaks are seen, but the precise period is poorly constrained. Right: Lyman α flux as a function of time, as well as the best-fit candidate periods. The shaded blue areas show our ideal requested observing windows to best measure the true period (or rule out periodicity). Observations obtained at the current epoch will clearly distinguish between the candidate periods: based on the uncertainty of the most recent Lyman α measurement, there is a $> 6\sigma$ difference between the predicted fluxes for 524 d and 973 d periods.

data, so searches for stellar cycles and/or rotation at these stars could be designed using only a small amount of *HST* time per star.

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Description of the Observations

We request two visits of two orbits each using STIS/G140M to obtain observations of the Lyα emission line. This observing setup has been used in the previous observations of this target (GO #14462, #14757, and #15071) and been verified to return sufficient SNR to

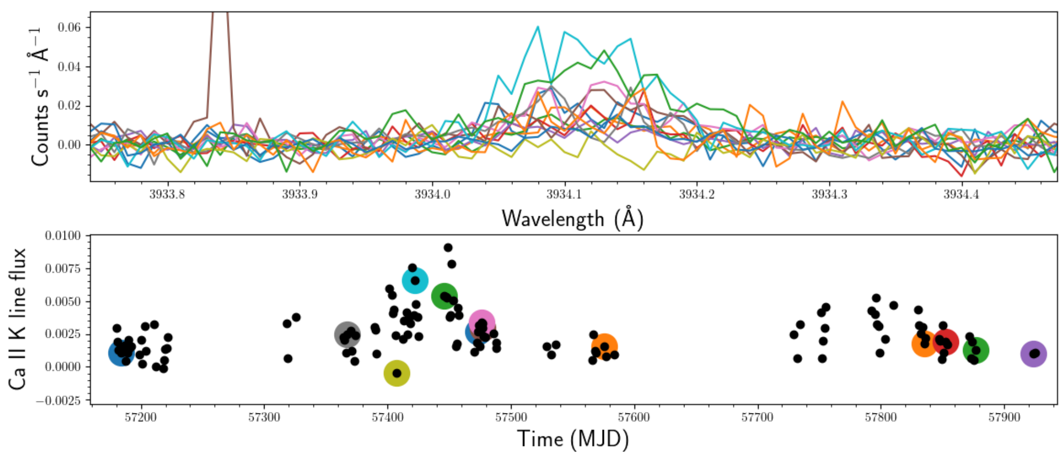

Figure 4: Top: HARPS spectra of GJ 1132 showing the Ca II H&K lines. Bottom: Light curve of the integrated fluxes from the spectra, with the example spectra shown in the top plot color-coded. The lines are only weakly detected and no continuum is detected, and the scatter on the light curve is too high to reliably measure a stellar cycle.

reconstruct the intrinsic (ISM-corrected) profile of the line and measure its flux and velocity centroid. The target has also been cleared for bright object protection for M stars in this observing mode.

Scheduling Requirements

Discriminating between the best-fit periods to the existing data requires the observations to be obtained before MJD≈59000 (end of May 2020) at the latest, separated by at least one month. There is no strong requirement for a disruptive turn around, however the first observation should ideally be obtained as soon as possible after the limit, i.e. three weeks after submission. We have therefore scheduled visits for any time in March and any time in May in the APT.