ARECIBO REDS: THE STELLAR ACTIVITY OF STARS WITH POTENTIALLY HABITABLE PLANETS.

K. N. Ortiz-Ceballos[1,2], A. Méndez[2], J. Zuluaga[3], R. Heller[4], D. Alexander[5], A. Pacini[2], [1]Department of Physics, University of Puerto Rico Río Piedras Campus, San Juan, PR, USA (kevin.ortiz22@upr.edu), [2]Planetary Habitability Laboratory, University of Puerto Rico at Arecibo, Arecibo, PR, USA [3]Universidad de Antioquía, Medellín, Colombia [4]Max Planck Institute for Solar System Research, Göttingen, Germany, [5]Rice University, Houston, TX, USA.

Introduction: Red dwarf stars are by far the most numerous stars in the galaxy, and their stellar activity is of special interest due to the potential of these stars to support habitable planets around them [1,2]. Planets around these stars could experience tidal locking, strong stellar magnetic fields, strong flares and high ultraviolet and X-ray fluxes, all factors that might affect their habitability. They may affect the long-term ability to retain water and other astrobiologically relevant volatiles in the atmospheres of any planetary bodies, and may cause atmospheric erosion [3,4,5]. Significant stellar activity may affect the bounds of the planets Habitable Zone.

Furthermore, a particular concern is that ultraviolet radiation is a key component in the reactions that give rise to precursor molecules to the main building blocks of living organisms such as amino acids and ribonucleotides under the Primordial Soup theory. Without sufficient ultraviolet radiation, these reactions may not yield sufficient products to generate precursor molecules, or may not take place at all. Assuming a young Earth atmosphere and consistent ultraviolet activity throughout a star's lifetime, *Rimmer et al.* defined an Abiogenesis Zone wherein precursor molecules are generated at a 50% yield [6]. Constant flaring activity could increase ultraviolet flux from a star and thus affect the placement of its Abiogenesis Zone.

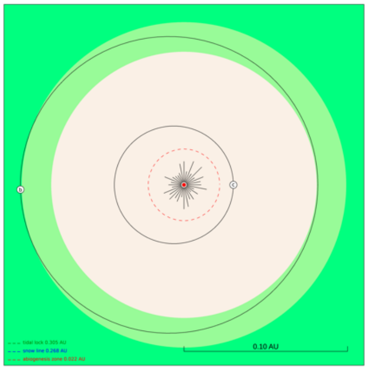
Stellar flares are associated with detectable radio emissions. Radio emissions from cool dwarfs are strong, but the absolute fluxes are small and impose severe constraints on the sensitivity of the instrument used to observe them. The Arecibo REDS project exploits the suitability of the Arecibo Observatory for obtaining accurate measurements of variable sources even when their emissions are faint.

Stars Observed: So far, 17 nearby red dwarf stars have been observed as part of the project. However, efforts have focused on three main targets: Barnard's Star (GJ699), Luyten's Star (GJ 273) and Ross 128 (GJ 447).

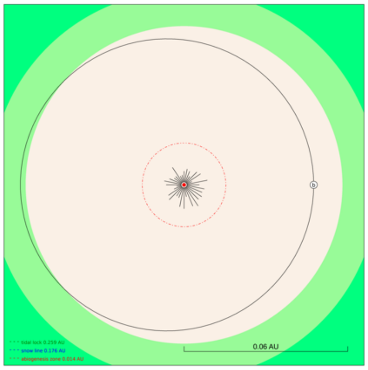
Table 1 Stars observed as part of Arecibo REDS

Name	Type	D (pc)
GJ 699 (Barnard's Star)	**M4V**	**1.8**
GJ 406 (Wolf 359)	M6V	2.4
GJ 411 (HD95735)	M2+V	2.5
GJ 447 (Ross 128)	**M4V**	**3.4**
GJ 280 (* alf CMi)	F5IV	3.5
GJ 1111 (G 51-15)	M6.5V	3.6
GJ 273 (Luyten's Star)	**M3.5V**	**3.7**
GJ 388 (BD+20 2465)	M4Vae	5.0
GJ 702 (* 70 Oph)	K0-V	5.1
GJ 3379 (G99-49)	M3.5Ve	5.2
2MASSI J1835379+325954	M8.5V	5.4
GJ 752 B (VB 10)	M8V	5.9
GJ 222 (* chi01 Ori)	G0V	8.8
GJ 436 (Ross 905)	M3V	10.2
GJ 398 (V* RY Sex)	M4V	15.3
GJ 1115 (BD+35 1890)	K3	26.2
K2-18	M2.5V	38.0

In 2017, two planets were discovered orbiting Luyten's Star [7]. One of these, the outer planet, is in the habitable zone, a Super-Earth of mass 2.89 M⊕ and a period of 18.7 days. Ross 128 has a planet close to the inner edge of the habitable zone, with mass 1.38 M⊕ and a period of 9.9 days [8]. A planet was discovered in 2018 around Barnard's Star, with a minimum mass of 3.2 M⊕ and a period of 233 days, but it does not lie in the habitable zone [9].



Luyten's Star



Ross 128

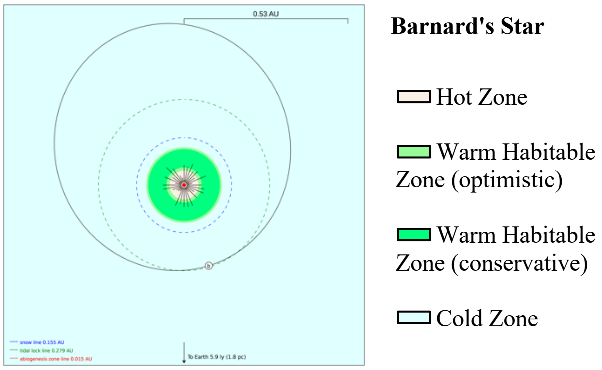


Figure 1: Exoplanet orbits and orbital thermal zones around main target stars.

The main target stars are not known to be particularly active, but even red dwarfs that are not very active, such as Proxima Centauri, are known to emit short-period bursts of about a minute with a peak flux density of 100 mJy, over 1000 times their quiescent emission [10].

Observation Details: Arecibo is the ideal instrument for these observations as it provides the ability to accurately and sensitively measure rapid source variability thanks to its single, large 305 meter dish. Stellar phenomena such as strong flares and rapid changes in flux densities can be precisely recorded with the instrument, though a trade-off is made with regards to sensitivity to quiescent emissions [11]. Observations have a remarkable temporal resolution of 0.1 s and frequency resolution of ~24 kHz.

Observational Approach. The project's observational approach has centered around carrying out both long (~10 minute) and short (~3 minute) interval observations. Long interval observations allow a more complete characterization of a star's relative variability and exploiting Arecibo's sensitivity, particularly when various long interval observations are performed back to back. On the other hand, short interval observations allow for more precise measurement of absolute fluxes. A mix of both types of interval observations provides the most complete characterizations.

Calibration and Interference Elimination. Switched noise diode and position switching calibrations were used. Measurements were gain-corrected by bootstrapping off standard continuum source targets with known, stable flux densities, such as quasars (*e.g.* B1140+223) [12]. Precision of gain-corrections was confirmed by verifying telescope pointing for both target star and calibration continuum source observations. Radio-frequency interference is minimized by selecting frequencies with minimum interference and recognized by their frequency range and lack of dispersion patterns. Interference due to weather and atmospheric conditions has been identified and ruled out as being of astronomical interest by monitoring changes in temperature, humidity and precipitation at the Observatory.

Results. Short 3 min and long 20-30 min flares in various target stars have been observed, and the three main target stars have been observed for long enough to have initial characterizations of the frequency of their flaring events, presented below. Further results will be released once the analysis of the data is completed.

Conclusion: We have been able to put initial constraints on the radio emissions from two of our main targets. So far, upper bounds on the flaring event frequency have been determined for these stars, shown in Table 2. Results for Ross 128 are still pending further analysis.

Table 2 Initial constraints on activity of target stars

Star	Flaring Time	Total Observed Time	U
GJ 699 (Barnard's Star)	180s	16500s	0.01091
GJ 273 (Luyten's Star)	2400s	26100s	0.09195
GJ 447 (Ross 128)	-	8340s	-

Note: U=Upper bound on frequency of flaring events.

Further characterizing the strength, frequency and spectra of the radio emissions of red dwarfs with potentially habitable planets will enable us to constrain the associated planetary impact and inform the potential for stable habitable conditions. We will model the long term impact of these stellar events on the atmospheric volatiles of their planetary bodies. Furthermore, estimating the water loss rate of these planets, it will be determined which are more likely to retain a large inventory of water today and are therefore the best targets for the search for biosignatures by future missions. Effects on the placement of the Abiogenesis Zone in our target systems will likewise be explored.

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