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The discovery of TRAPPIST-1 and the importance of low-mass M-dwarfs

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The TRAPPIST-1 system — seven Earth-sized worlds around a tiny star — reshaped exoplanet science, proving that faint low-mass M-dwarfs are prime targets in the search for habitable planets and life beyond Earth.

The discovery that would redefine our search for habitable worlds began in 2016 and culminated in 2017, when Michaël Gillon and colleagues announced that the ultracool M-dwarf TRAPPIST-1, a mere 39 light-years away, hosts a system of seven Earth-sized exoplanets[1,2]. The finding emerged from transit observations by the ground-based TRAPPIST telescope and NASA's Spitzer Space Telescope. Three planets were nestled within the star's classical Habitable Zone—where liquid water could exist on the surface—while the others spanned a variety of climates, from freezing to scorching.

TRAPPIST-1's architecture is nothing short of astonishing. All seven planets orbit closer than Mercury does to our Sun, completing their "years" in just 1.5–20 days. Their compact configuration, revealed through meticulous transit-timing variations, allowed extremely precise mass and density estimates confirming rocky compositions[3,4]. Crucially, the star's diminutive size (9% the Sun's radius) amplified transit signals, making atmospheric studies feasible. This system became an instant laboratory for comparative planetology.

Subsequent characterization has revealed the TRAPPIST-1 system's key properties. The planets' orbits form a resonant chain, a configuration that suggests they formed farther out and migrated inward early in the system's history, maintaining remarkable orbital stability over its likely ancient age [5]. Precise density measurements confirm their rocky nature but indicate they are less dense than Earth. This suggests potentially large volatile inventories, with some models proposing that the outer planets could be water-worlds [4]. This compositional gradient supports a formation scenario in a water-rich region of the protoplanetary disk [6]. TRAPPIST-1 has thus provided a foundational case study for understanding the formation and evolution of compact planetary systems.

What made TRAPPIST-1 truly transformative, however, was how it overturned expectations. At the time, most exoplanet surveys focused on Sun-like stars, with low-mass M-dwarfs largely regarded as second-tier targets. Few anticipated that such a small, faint star could host a rich, tightly packed system of terrestrial planets—including several in the habitable zone. The discovery electrified both scientists and the public, but its enduring legacy was to shift the community's focus: the lowest-mass M-dwarfs, the Galaxy's silent majority, suddenly became prime hunting grounds for habitable worlds.

The smallest M-dwarfs offer unrivalled advantages for detecting and characterizing temperate Earth-sized planets. Their low luminosity compresses habitable zones inward, yielding short orbital periods and frequent transits—TRAPPIST-1 b orbits in just 1.5 days. The planet-to-star size ratio also boosts transit depth: TRAPPIST-1's signals are an order of magnitude deeper than Earth's around the Sun, enabling atmospheric reconnaissance. Radial velocity signals are stronger as well since planets exert a greater gravitational tug on these low-mass hosts.

All these characteristics make M-dwarfs prime targets to look for signs of extraterrestrial life. Still, such stars present astrobiological challenges. They are magnetically active, producing flares and X-rays that can strip atmospheres, and their planets are often tidally locked, with hemispheres locked in perpetual day or night. Yet if these worlds are geologically active or shrouded in dense atmospheres, they may redistribute heat and retain surface water[7]. This tension between detectability and survivability lies at the heart of the debate on their habitability.

Beyond TRAPPIST-1, other nearby ultracool dwarfs highlight their promise. Proxima Centauri b remains one of the most scrutinized temperate worlds despite its star's activity [8,9]. This promise is continually validated, with recent discoveries like the Earth-sized SPECULOOS-3 b [10] further populating this category of readily detectable, rocky worlds. These examples demonstrate why the faintest stars in the Galaxy, long overlooked in exoplanet surveys, are now at the forefront of the search for habitable worlds.

The coming decade will rigorously test whether planets around ultracool M-dwarfs can sustain life. JWST has begun probing the TRAPPIST-1 system, but initial atmospheric studies highlight the challenges: stellar activity and the need for extensive data can obscure signals. Early emission photometry results for the innermost planets suggest they may lack substantial atmospheres, showcasing the power of this technique [11,12]. However, the search for atmospheres on the habitable-zone planets (e, f, g) is ongoing and remains a top priority.

The next generation of ground-based giant telescopes (e.g., the ELT) will extend these studies to non-transiting planets. High-resolution spectroscopy may enable a direct search for molecular oxygen on Proxima b. Ariel (set for launch in 2029) will complement these efforts by surveying hundreds of exoplanet atmospheres, with a strong focus on M-dwarfs.

In the longer term, direct-imaging missions such as the Habitable Worlds Observatory (HWO) will extend atmospheric studies to Earth analogs around Sun-like stars, where transit and occultation techniques are not applicable. Meanwhile, theory must keep pace: coupled climate–geochemistry models are needed to explore how M-dwarf planets might maintain stability under persistent stellar activity.

TRAPPIST-1 has taught us that even the smallest stars can host rich planetary systems. If M-dwarfs, the Galaxy's most common stars, can host habitable worlds, then the chances of life beyond Earth may be far greater than we once imagined.

Competing Interests
The author declares no competing interests.

Figure 1 | Known temperate rocky planets orbiting nearby low-mass stars. Planets discovered by the TRAPPIST and SPECULOOS surveys are indicated by circles. Those for which TRAPPIST and SPECULOOS contributed to the discovery are marked by hexagons. The others are indicated by triangles. The colours indicate the planets' orbits in reference to the classical Habitable Zone (red: inward; green: within; blue: outward). [Credit, SPECULOOS collaboration].

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