Interactive Website for Visualizing Habitability in Exoplanet Systems

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Abstract

This project introduces a browser-based application for visualizing habitable zones (HZs) and orbital configurations of exoplanetary systems. Using stellar parameters of 4,134 systems retrieved from the NASA Exoplanet Archive. Systems with high ESI planets have also been highlighted for ease of access. HZ boundaries are defined as the runaway and maximum greenhouse limits with Kopparapu et al. (2014) [1] model. The inner edge is mass-dependent and plotted for 0.1, 1.0, and 5.0 $M_\oplus$ to reflect differences in atmospheric heat retention; the outer edge is treated as nearly mass independent. Each static diagram includes orbital layout plotted alongside the HZ, stellar placement on a Hertzsprung–Russell (HR) diagram, and access to system parameters. Users may also define custom systems. The web application is accessible at www.exoplanetvisualizer.com

Keywords: Web Application, Habitable Zone, Exoplanet

Introduction

The habitable zone (HZ) is the region around a star where liquid water could exist on a planet's surface under plausible atmospheric conditions. This application computes HZ boundaries using stellar parameters from the NASA Exoplanet Archive and the model by [1]. The outer edge, based on the maximum greenhouse effect, is treated as constant across planetary masses. The inner edge varies with mass and is plotted for 0.1, 1.0, and 5.0 $M_\oplus$. Users can display any individual inner edge or a combined view showing all three as layered shaded regions. In combined mode, each additional mass adds a nested HZ boundary, with a zoomed in-set improving clarity in the inner regions. Each system is rendered as a static diagram showing orbits and HZs, with a corresponding HR diagram. Users can also input custom stellar and planetary parameters.

Objectives

1. To develop a browser-based platform for visualizing planetary orbits and habitable zone (HZ) boundaries using stellar parameters.
2. To integrate static orbital diagrams and dynamic simulations to illustrate how stellar parameters influence potential habitability of planets in the system.

Methodology

Data Collection

Stellar and planetary parameters for 4,134 systems were retrieved via a TAP query to the NASA Exoplanet Archive and stored as structured JSON. Each entry contains star name, mass (M⊙), luminosity (L⊙), effective temperature (K), radius (R⊙), and a list of planets with names, masses (M⊕), semi-major axes (AU), and orbital periods (earth days).

Interface

Users interact via a browser-based frontend. They can select from preset systems or input custom stellar and planetary parameters. These inputs are sent to the backend, which generates and returns 2 base64-encoded SVG images: a static orbital diagram with overlaid HZ boundaries and a separate HR diagram. Meanwhile, the D3.js orbit simulator on the client-side updates instantly using local JSON data, with hover information tooltips on planets and the star, adjustable speed and zoom, start/stop controls, randomized orbital positions.

Computational Framework

HZ boundaries are computed using the model from [1], with the inner edge calculated for 0.1, 1.0, and 5.0 M⊕ to reflect mass-dependent greenhouse effects; the outer edge is plotted as a single curve due to its weak mass sensitivity. Static plots are rendered using Matplotlib, while the orbit simulator in D3.js animates circular orbits based on semi-major axis and period. The HR diagram uses a proportionally scaled temperature axis between stellar classes to improve visual separation of stars with similar effective temperatures, allowing finer distinctions within closely grouped spectral types. Orbital mechanics assumptions are discussed in the theoretical background.

Deployment and Access

The site is deployed via Vercel and publicly accessible at www.exoplanetvisualizer.com Cloudflare handles DNS resolution and edge caching. The site can be accessed from any modern browsers.

Figure 1 Orbital & HR diagram

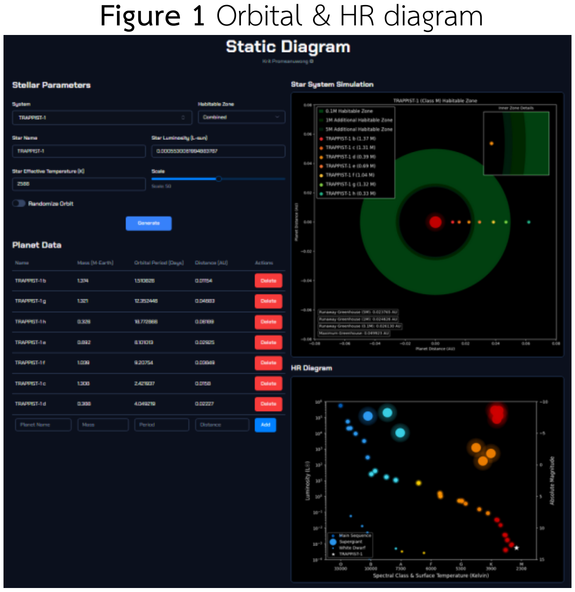
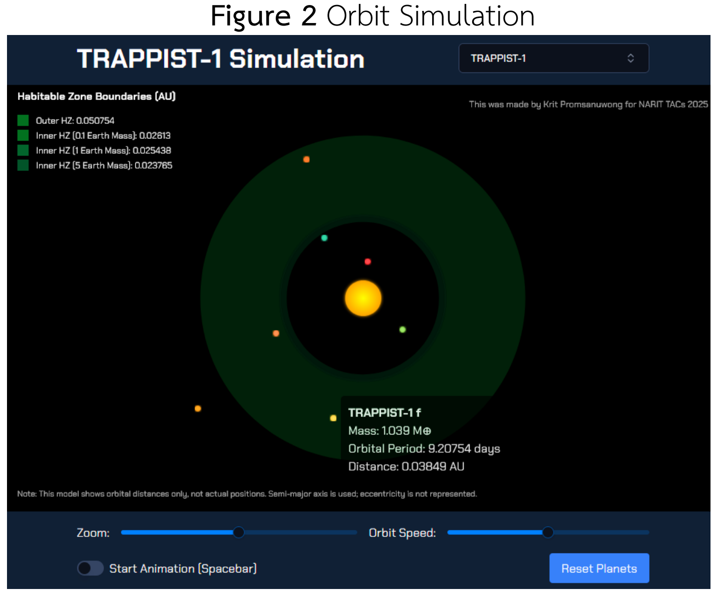


Figure 2 Orbit Simulation



Theoretical Background

The concept of the habitable zone (HZ) provides a *preliminary estimate* of the region around a star where a terrestrial planet could sustain surface liquid water, assuming plausible atmospheric conditions. Following the framework established in [1] , we refine HZ boundaries by incorporating both stellar properties and planetary mass. Two principal limits define the zone: the inner edge, where a runaway greenhouse effect causes complete atmospheric water loss, and the outer edge, where even a maximal CO_2 greenhouse cannot prevent glaciation.

$$S_{\text{eff}} = S_{\text{eff}\odot} + a\,T + b\,T^2 + c\,T^3 + d\,T^4$$

Where $T = T_{eff} - 5780K$. Coefficients $S_{\text{eff}\odot}$,a,b,c,d vary depending on boundary criteria and planetary mass assumptions, as shown in **Figure 3**, and based on the dataset published by [1]. The corresponding orbital distance is determined by $d = \sqrt{\frac{L*/L\odot}{S_{\text{eff}}}}$ in AU

Coefficients	Maximum Greenhouse	Runaway Greenhouse 0.1 M⊕	Runaway Greenhouse 1 M⊕	Runaway Greenhouse 5 M⊕
$S_{\text{eff}\odot}$	0.356	0.99	1.107	1.188
A	6.171e-5	1.209e-4	1.332e-4	1.433e-4
B	1.698e-9	1.404e-8	1.58e-8	1.707e-8
C	-3.198e-12	-7.418e-12	-8.308e-12	-8.968e-12
D	-5.575e-16	-1.713e-15	-1.931e-15	-2.084e-15

Figure 3 HZ Boundary Coefficients

We compute the inner (runaway greenhouse) boundary for three cases—Mars-like (0.1 M⊕), Earth-like (1 M⊕), and Super-Earth (5 M⊕) by assuming background N_2 pressure scales with surface gravity. While volatile delivery mechanisms introduce variability, this gravity-based approach provides a practical first-order estimate consistent with existing exoplanet atmospheric models and aligns with the assumptions made by [1]

The outer edge of the habitable zone, defined by the maximum greenhouse limit, varies minimally with planetary mass and is plotted as a single curve. For the inner edge, users can choose to display the runaway greenhouse boundary for a specific planetary mass 0.1 M⊕, 1 M⊕, or 5 M⊕ to reduce visual clutter. A combined view is also available, showing nested inner boundaries where each additional mass adds an incremental layer to the HZ. In this mode, the full HZ for 5 M⊕ includes all inner zones for 0.1 and 1 M⊕. To address previous clarity issues, the combined version includes an in-set zoom that highlights closely spaced inner boundaries. Shaded regions represent cumulative extensions rather than separate or overlapping zones.

Results

The web application deployed at www.exoplanetvisualizer.com is accessible from any modern browser and contains 4,134 systems sourced from NASA Exoplanet Archive. The static orbital graph generator produces precise two-dimensional plots of planetary orbits and habitable zone (HZ) boundaries. The computed HZ boundaries for 4 sample systems, are displayed in Figure 4. These values match those computed by the Kopparapu et al.'s HZ Calculator [3] when given the same parameters, ensuring accuracy. The Hertzsprung–Russell diagram overlays the target star onto a background of 59 reference stars, positioned by temperature and luminosity. The D3.js orbit simulator renders circular orbits based on semi-major axes and orbital periods, with controls for animation speed, alignment and a hoverable information tooltip.

Criteria / Star	Outer HZ (Maximum Greenhouse)	$0.1M\oplus$ (Runaway Greenhouse)	$1M\oplus$ (Runaway Greenhouse)	$5M\oplus$ (Runaway Greenhouse)
Solar	1.676	1.005	0.950	0.917
TRAPPIST-1	0.050	0.026	0.024	0.023
Kepler-47	1.438	0.859	0.812	0.784
Kepler-296	0.348	0.192	0.181	0.175

Figure 4 Calculated Habitable Zone for Sample Systems

Conclusion

This project delivers a static, browser-based platform for visualizing habitable zones and orbital configurations of exoplanetary systems. It combines empirically validated HZ boundary models with accurate orbital plots and a proportion-scaled Hertzsprung–Russell diagram for stellar context. All computed HZ distances match calculated values from [3] given the same parameters albeit with more decimal precision, and stellar placements appear consistent with NASA Models. The result is a browser-based tool that requires no local installation or server dependencies, making it ideal for both educational use and preliminary exoplanet research.

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References

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