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The Exo.MAST Table for JWST Exoplanet Atmosphere Observability

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INTRODUCTION

As we approach the launch of the James Webb Space Telescope (JWST), exoplanet scientists will need to be able to determine which exoplanets are the best suited for atmospheric characterization through transmission and emission in the near- and mid-infrared wavebands. A host of exoplanet databases provide the portions of the needed information to determine this; however, none readily calculate the atmospheric scale height and day-side temperatures, parameters necessary to determine atmosphere signal strength.

The Mikulski Archive for Space Telescopes (MAST) has released the Exoplanet Atmosphere Observability Table[1] to allow users to sort and filter exoplanets by the expected signal strength when trying to detect exoplanet atmospheres with JWST. The table provides pre-calculated signal-to-noise (SNR) metrics that are useful to estimate the relative signal strength observed for one transit (or eclipse), measured at infrared wavebands. The exoplanet database it relies on is the same as that used by exo.MAST,[2] and contains the parameters provided by the NASA Exoplanet Archive composite table[3], Exoplanets.org[4] and the TESS Objects of Interest Table[5]. The following note is a description of the SNR calculations provided in this table and how they can be used to select targets for exoplanet atmosphere characterization.

EMISSION AND TRANSMISSION SIGNAL-TO-NOISE VALUES

This observability table provides three SNR values to quickly compare the expected strength of atmosphere emission and transmission observations in the infrared. These values are similar to those presented by Kempton et al. (2018), but account for eclipse/transit durations and are tuned for JWST observations by using K-band magnitudes. These SNR values are calculated for specific infrared wavelengths based on the measured properties of the exoplanets and the stars they orbit. Each is calculated relative to the reference (ref) planet HD 209458 b, a transiting hot Jupiter. The calculations that generate the SNR values are available on GitHub[6](Stevenson 2018).

The emission SNR value (E_λ) for the specified wavelengths (λ =1.5 and 5 microns) derives from calculating the flux from the planet relative to the flux from the star at the specified wavelength.

$$E_\lambda = \frac{F_p}{F_*}\frac{F_{*,ref}}{F_{p,ref}}\sqrt{10^{-0.4(K-K_{ref})}}\sqrt{\frac{d}{d_{ref}}} \tag{1}$$

where F_p and F_* are the blackbody fluxes (with bond albedo equal to zero) at the specified wavelengths for the planet and the star, respectively. The exoplanet temperature for the blackbody is given by the equation:

$$T_{day/eq} = T_*\sqrt{\frac{1}{a}}\left(\frac{1}{4f}\right)^{\frac{1}{4}} \tag{2}$$

[1] https://catalogs.mast.stsci.edu/eaot
[2] https://exo.mast.stsci.edu
[3] https://exoplanetarchive.ipac.caltech.edu
[4] https://exoplanets.org
[5] https://tev.mit.edu
[6] https://github.com/kevin218/exoMAST_Obs

where a is the semi-major axis in units of stellar radii, T_* is the stellar temperature, and f is the heat redistribution factor. For the emission SNR, we adopt the day-side temperature (T_{day}), which assumes $f = 0.5$. The noise for the E_λ calculation only includes photon noise derived from the K-band magnitude assuming photons are collected for the full duration of the transit, d.

The transmission SNR for the K-band magnitude (T_K) derives from the ratio of the amount of star light that travels through one scale height (H) of the planet's atmosphere to the stellar flux. Since the scale height of the atmosphere is much smaller than the planet radius, the area blocked by the atmosphere is $2HR_p$, where R_p is the planet radius. The one-scale-height spectral feature size (δ_{atm}) can be estimated as:

$$\delta_{atm} = \frac{2HR_p}{R_*^2} \tag{3}$$

The planet atmosphere scale height is calculated as follows:

$$H = 1000\frac{RT_{eq}}{\mu g_p}, \tag{4}$$

where R is the ideal gas constant ($8.3144598\ J/mol/K$); μ is the mean molecular molar mass of one atmosphere of particles assuming a purely H_2/He atmosphere ($\mu = 2.3\ g/mol$); g_p is the planet gravity; T_{eq} is the planet equilibrium temperature calculated using Equation 2 with $f = 1$. The T_{eq} and T_{day} values are calculated (rather than relying on values provided in the literature) to ensure consistent re-radiation constants in the calculations.

The size of the noise is once again derived assuming Poisson statistics and the reported T_K is given relative to HD 209458 b. Thus, T_K is calculated as follows:

$$T_K = \frac{\delta_{atm}}{\delta_{atm,ref}}\sqrt{10^{-0.4(K-K_{ref})}}\sqrt{\frac{d}{d_{ref}}} \tag{5}$$

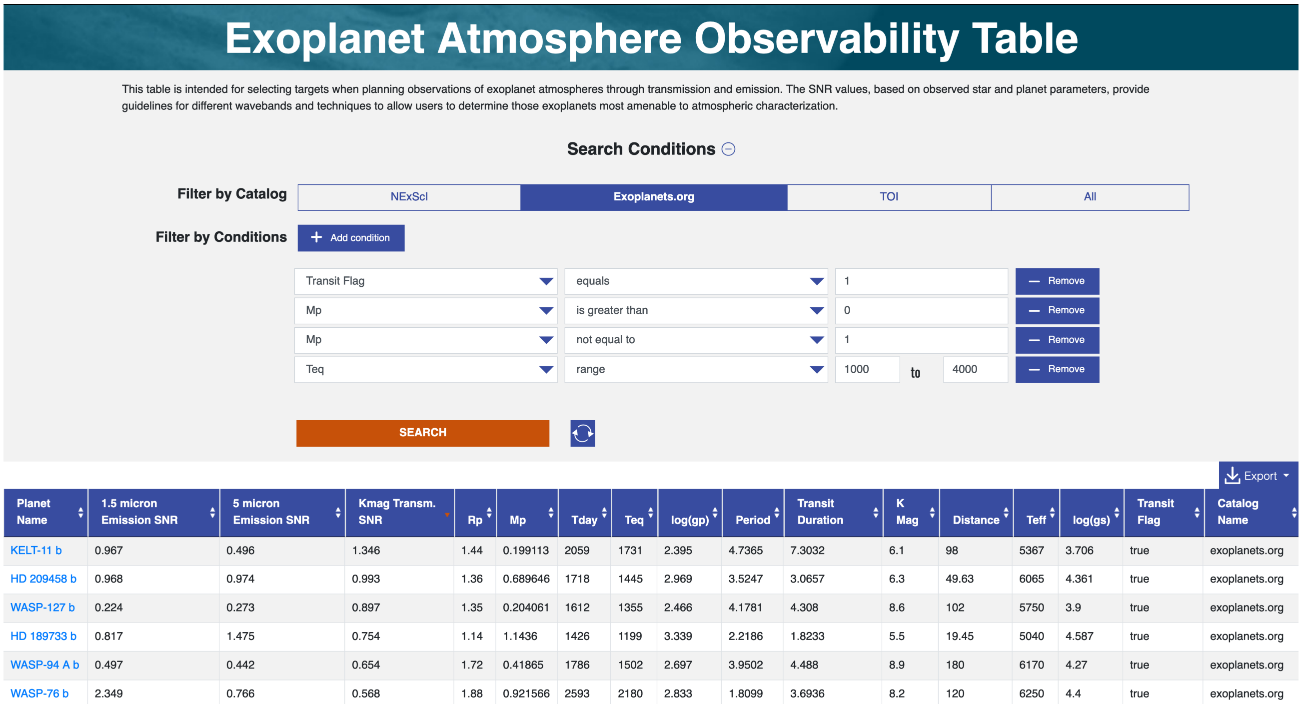
We adopt the following values for HD 209458 b, the reference planet for the above calculations: $K_{ref} = 6.308$, $R_{*,ref} = 1.1780230\,R_\odot$, $T_{*,ref} = 6077\,\mathrm{K}$ (Gaia Collaboration et al. 2018), $R_{p,ref}/R_{*,ref} = 0.12247$, $a_{ref}/R_{*,ref} = 8.814$, $M_{p,ref} = 0.73$ Jupiter masses (Stassun et al. 2017), and $d_{ref} = 0.1277$ days (calculated using Seager & Mallén-Ornelas 2003).

EXAMPLE USAGE

Figure 1 shows an example filter and sorting of the Exoplanet Atmosphere Observability Table. Each row of the returned table includes the exoplanet's name linked back to its exo.MAST page, the three SNR values described above, and common exoplanet properties. The resulting table can be exported as a csv file, VO Table, or JSON file.

While this table provides a simple way to identify those targets most amenable to atmospheric characterization with JWST, it is important to note that the scale height calculation assumes the atmosphere is pure H_2/He. Thus the relative SNR is invalid when comparing planets with vastly different compositions. However, SNR values are valid when comparing planets whose atmospheres have similar mean molecular weights. Exoplanet parameters are only as accurate as the underlying catalogs; users are encouraged to refer to the underlying papers as they finalize their target list. We recommend using the Exoplanet Characterization Toolkit[7] (ExoCTK), which is linked from the exo.MAST JWST Visibility tab for each planet, to plan JWST time series observations of the exoplanet atmosphere.

[7] https://exoctk.stsci.edu



Planet Name	1.5 micron Emission SNR	5 micron Emission SNR	Kmag Transm. SNR	Rp	Mp	Tday	Teq	log(gp)	Period	Transit Duration	K Mag	Distance	Teff	log(gs)	Transit Flag	Catalog Name
KELT-11 b	0.967	0.496	1.346	1.44	0.199113	2059	1731	2.395	4.7365	7.3032	6.1	98	5367	3.706	true	exoplanets.org
HD 209458 b	0.968	0.974	0.993	1.36	0.689646	1718	1445	2.969	3.5247	3.0657	6.3	49.63	6065	4.361	true	exoplanets.org
WASP-127 b	0.224	0.273	0.897	1.35	0.204061	1612	1355	2.466	4.1781	4.308	8.6	102	5750	3.9	true	exoplanets.org
HD 189733 b	0.817	1.475	0.754	1.14	1.1436	1426	1199	3.339	2.2186	1.8233	5.5	19.45	5040	4.587	true	exoplanets.org
WASP-94 A b	0.497	0.442	0.654	1.72	0.41865	1786	1502	2.697	3.9502	4.488	8.9	180	6170	4.27	true	exoplanets.org
WASP-76 b	2.349	0.766	0.568	1.88	0.921566	2593	2180	2.833	1.8099	3.6936	8.2	120	6250	4.4	true	exoplanets.org

Figure 1. Example view of the Exoplanet Atmosphere Observability Table filtered to show those exoplanets in the Exoplanets.org catalog that transit, have a planet mass listed, but not equal to 1 (a value used by Exoplanets.org when there is no measured mass), and have an T_{eq} between 1000 K and 4000 K. The results are sorted to show those with the largest T_K value.

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