Characterizing Exoplanet Atmospheres

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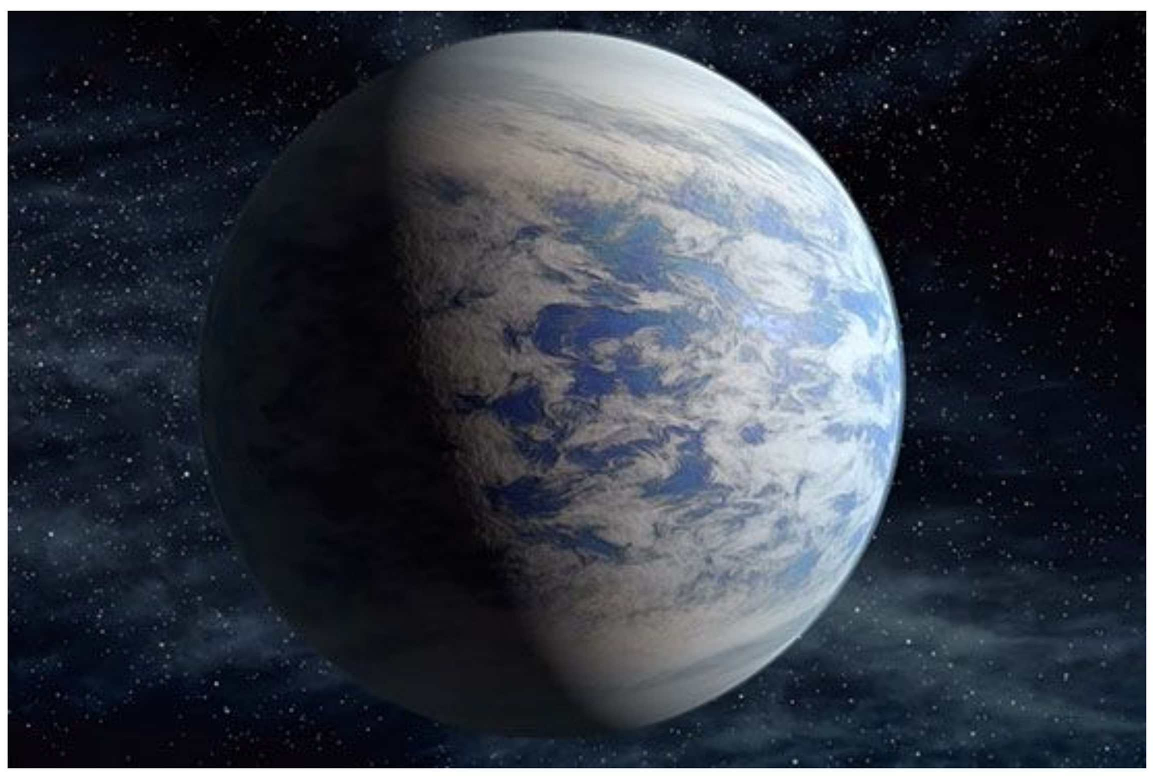
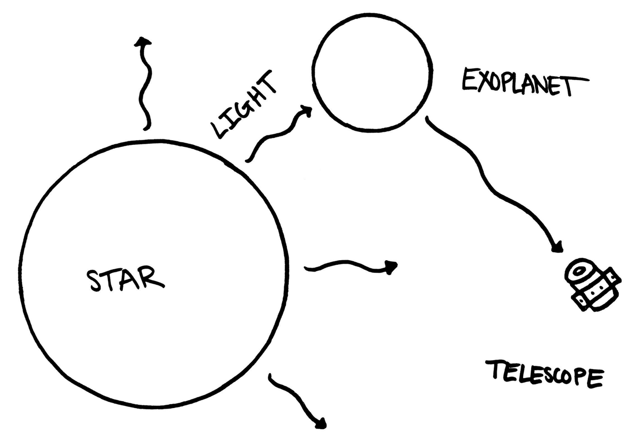
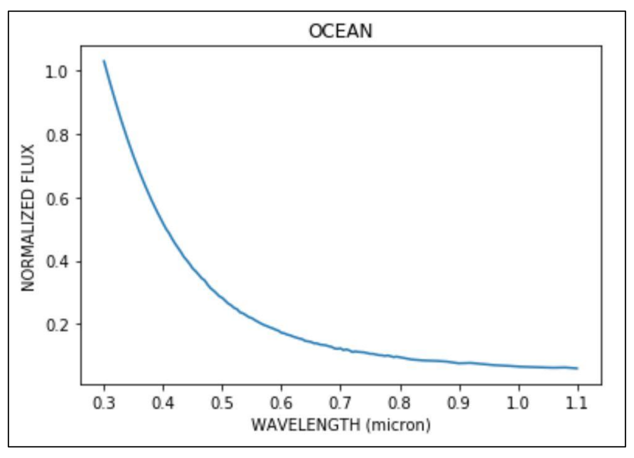
Introduction

Discovering life outside of the solar system, on planets around other stars known as exoplanets, would be the holy grail of astrobiology, the study of life in the Universe. In the next two decades, telescopes such as WFIRST will be able to measure the light from the exoplanets, which would appear as only a pixel on a screen. In order to be able to characterize the surface without resolving the planet requires measuring the spectra, which is the colors from the planet. This is similar to using a telescope to see if there is fruit, which represent planets, on distant trees, which represent stars, in a meadow-the only way to determine if there is fruit is to see the colors on the trees as they are too far away to resolve.

In this project, we studied the atmospheres and surfaces of various terrestrial exoplanets by doing analysis on different forms of spectra to determine what surface features it has. We then found the flux of the star and then the flux at which the telescope will see it at.







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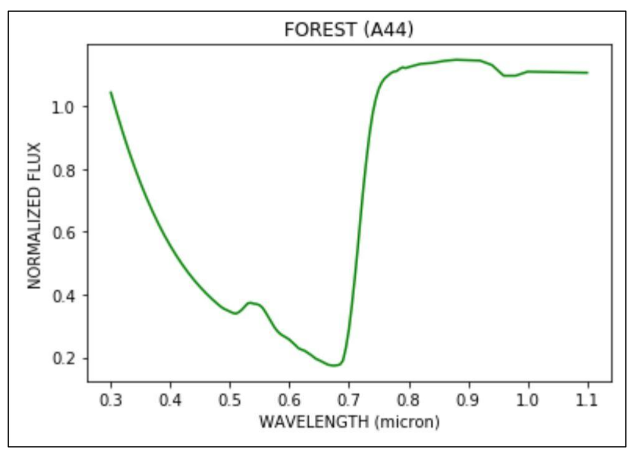

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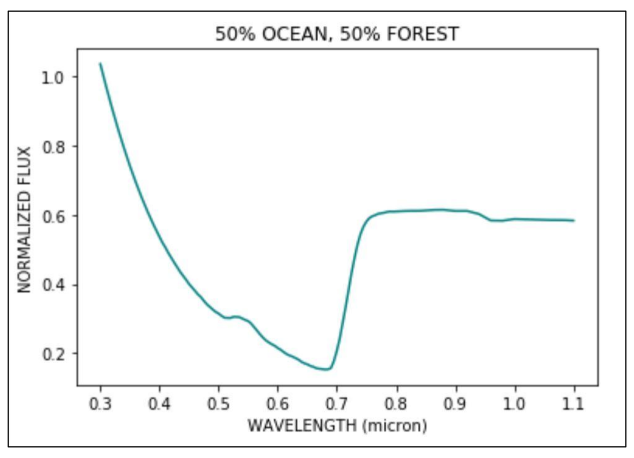

Methodology

From the star catalog, we selected one star, our closest star to work with, the M-star: Proxima Centauri. To find whether we can detect an Earth-like planet near the star we went to find the flux of the star. We knew that with the magnitude, we could calculate the flux values of the star. Using the apparent magnitude formula, solving for Fx, will give the flux of the star. The *magnitudes* were referenced from Simbad, and the fluxes were found at each different spectral waveband UBVRIJ -- consistent with our spectral wavelength bin 0.3 -- 1.1 μm. Using the flux of the star, we then combined it into a formula, that compared the ratio of the planets area and surface area, for finding the flux, of the nearby planet. For the distance we estimated a planet at 1.0 AU and 10 parsecs. Our final step was to find a telescope with sensitivity flux that would pick up our *planet*.

$$F_{star} = F_{x_0} \cdot 10^{-\frac{m}{2.5}} \qquad Fluxplanet = Fstar * \frac{\pi R_p^2}{4\pi d^2} \qquad m_x = -2.5\log_{10}\left(\frac{F_x}{F_{x,0}}\right)$$

Standard apparent magnitudes and fluxes for typical bands[9]

Band	λ (μm)	$\frac{\Delta\lambda}{\lambda}$ (FWHM)	Flux at $m = 0$, $F_{x,0}$	
			Jy	10^{-20} erg/(s·cm²·Hz)
U	0.36	0.15	1810	1.81
B	0.44	0.22	4260	4.26
V	0.55	0.16	3640	3.64
R	0.64	0.23	3080	3.08
I	0.79	0.19	2550	2.55
J	1.26	0.16	1600	1.60
H	1.60	0.23	1080	1.08
K	2.22	0.23	670	0.67
L	3.50			
g	0.52	0.14	3730	3.73
r	0.67	0.14	4490	4.49
i	0.79	0.16	4760	4.76
z	0.91	0.13	4810	4.81

Each one of our original models describes a surface feature, acting like a filter to help us determine if certain characteristics are present on an exoplanet. When multiple spectra are put together, unique combinations can be made. For example, a similar Earth-like planet could be *roughly* modeled as 80% ocean, 10% sand, and 10% forest. This allows us to find the best combination model to match the spectra from our simulated observations. The chi-squared technique can compare two graphs and the lowest chi-squared value can determine which model is the best fit.

$$\chi^2 = \Sigma\left(\frac{Observed - Expected}{Expected}\right)^2 \qquad OBS = MODEL \times STAR \times \left(\frac{r^2}{4d^2}\right)$$

Results

For the M-star, proxima centauri, a planet at a distance of 1.0 AU, and 10 parsecs, its flux will meet the WFIRST, minimum needed flux, which is set at 0.5*10^-16 ergs. Our planet will be picked up and its spectra observed. WFIRST can be used for our model spectra -- it carries a spectrometer with equipment that reads spectra at 0.4 - 1.0 μm. **Our model spectra wavelength band is from 0.3 - 1.1 μm.**

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HIP 85665 9.98302885095
HIP 8362 9.97605746209
HIP 102409 9.94134605826
HIP 84581 9.9117851125
HIP 71898 9.86777185711
HIP 31635 9.84348853234
HIP 47780 9.81643270835
HIP 72944 9.81257972721
HIP 81300 9.77803852547
HIP 86057 9.77517106549
HIP 82003 9.77039570103
HIP 61629 9.65810314854
HIP 46655 9.6562379297
HIP 56997 9.54107432497
HIP 56452 9.53834414346
HIP 47425 9.49307005886
HIP 86776 9.48856627764
HIP 9786 9.46611132147
HIP 9724 9.43930526713
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['Flux of star M-star', 'HIP', '70890', 'M5Ve', 'U', 'B', 'V', 'R', 'I', 'J BAND']
['HIP 70890 M5Ve']
3.747e-06, 2.8146e-05, 0.00010993, 0.000511, 0.001966, 0.011516

['Flux Exoplanet near M-star 1.60 ergs 1.0 AU', '1.2 parsec']
1.785429844e+11

['Flux Exoplanet near M-star 1.60 ergs 1.0 AU', '10 parsec']
2571018975.0
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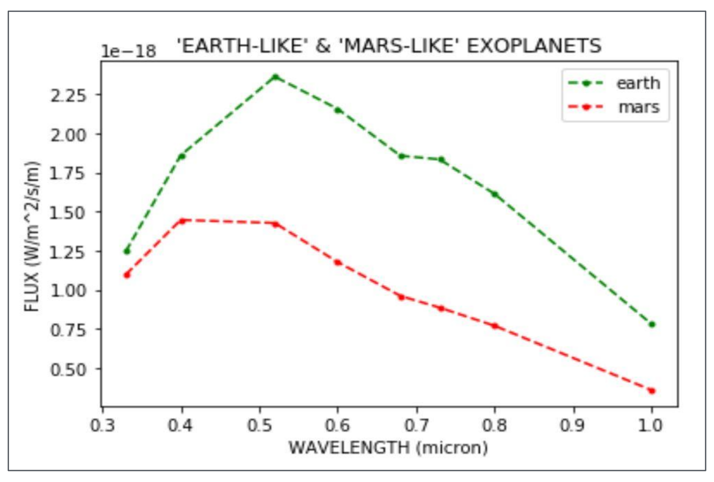

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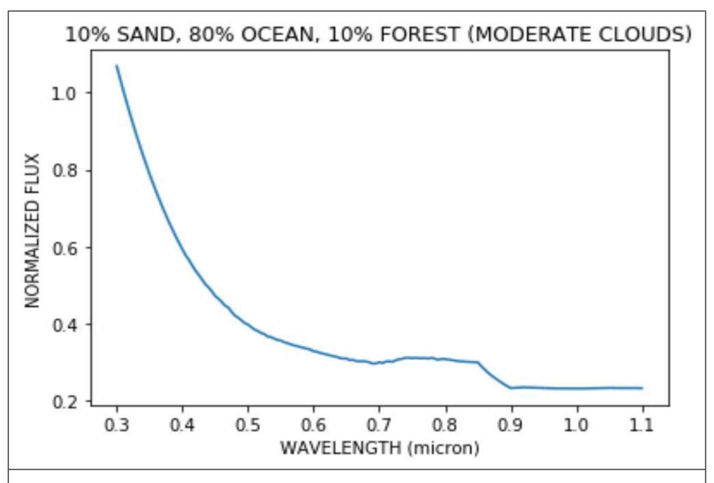

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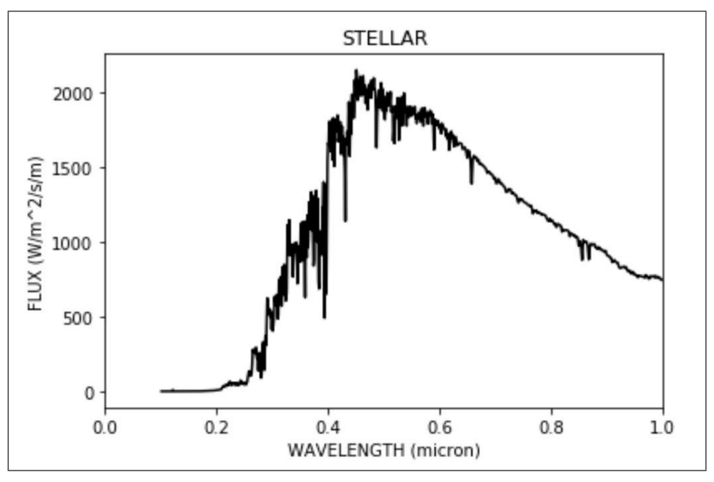

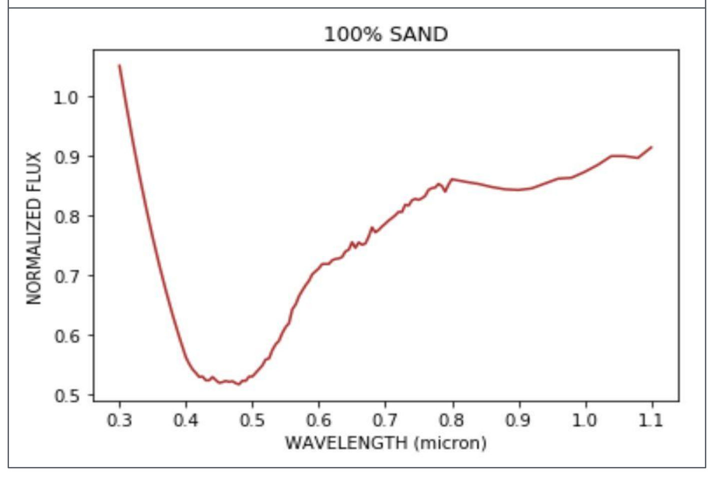

For the "Earth-like" exoplanet, a combination of 10% sand, 80% ocean, and 10% forest with intermediate clouds resulted in the best fit. A 100% sand model fitted the best to the "Mars-like" exoplanet.

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'EARTH'
CHI-SQUARED:  0.0001665325400817441

'EARTH' (wrong combination)
CHI-SQUARED:  20.472026203682674

'MARS'
CHI-SQUARED:  0.0011946091235912944
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Discussions and Conclusions

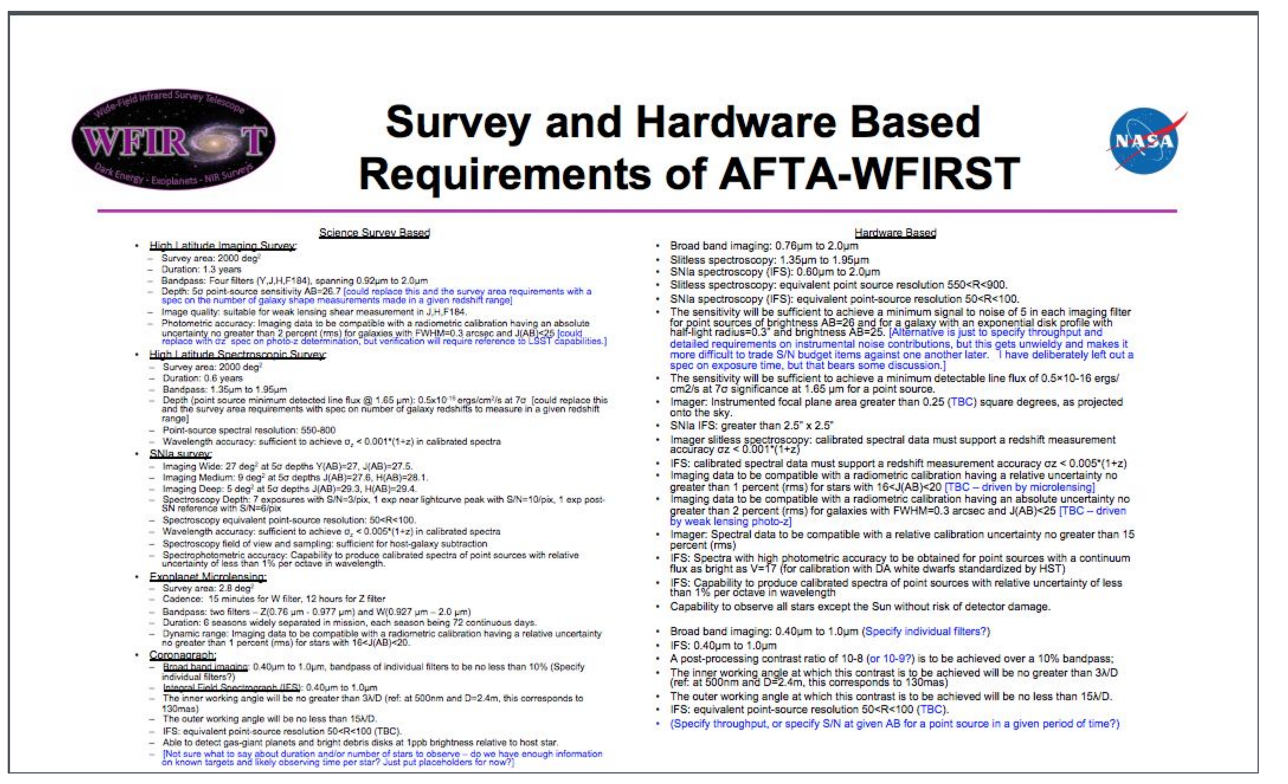
We practice using simulated observations to improve our models to prepare us for when we obtain real data.

Knowing the limitations on our instruments helps us determine the limitations of our models and how we can improve them.

Being able to identify surface features will help us explore the universe and will potentially lead to the discovery of life.

The improvement of our telescopes will also help us directly observe features of exoplanets, which has never been done before.

WFIRST Capabilities



Survey and Hardware Based Requirements of AFTA-WFIRST