

Kepler Data Analysis

Richard Anderson



Fork updates:

<https://github.com/Rander417/KeplerExoplanet>

- New presentation
- Raw data pulled from CSV initially
- Pickled key data sets
- Refactored “habitable zone” analysis

Forked from team project:

<https://github.com/tom-ij-G/KeplerExoplanets>

Columbia University – Fu School of Engineering

- Data Analytics 6mo Program

My role was building the ML pipeline

- Data Cleaning
- EDA
- Preprocessing
- Building the ML models

Teammates:

Damien Corr, Priscilla Lin, Tom Greff

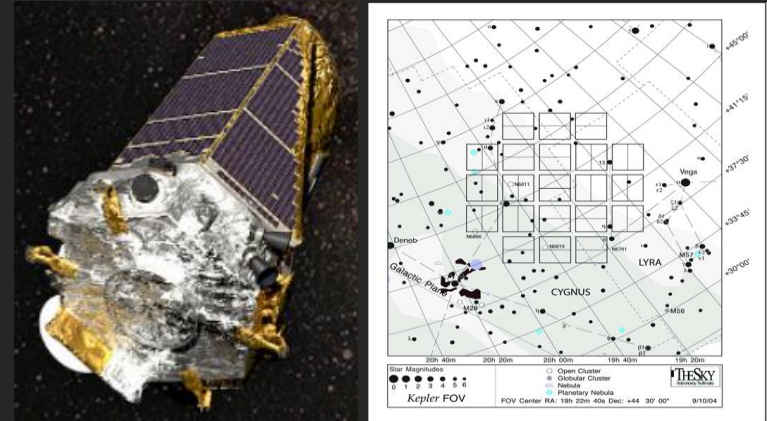
Kepler Mission Overview

“Designed to survey our region of the Milky Way galaxy to discover hundreds of Earth-size and smaller planets in or near the habitable zone and determine the fraction of the hundreds of billions of stars in our galaxy that might have such planets.”



https://www.nasa.gov/mission_pages/kepler/overview/index.html

Kepler Field of View (FOV)



https://www.nasa.gov/mission_pages/kepler/overview/index.html

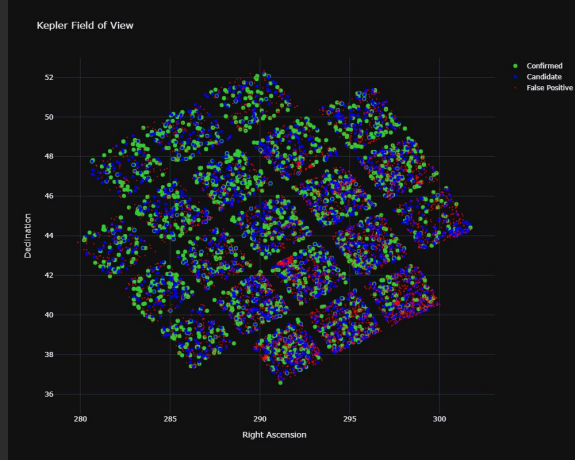
The Kepler Telescope's photometer consists of 21 CCD modules, each with two 2200x1024 pixel CCDs for a grand total of 94.6 million active pixels.

<https://keplerscience.arc.nasa.gov/the-kepler-space-telescope.html#:~:text=entering%20the%20telescope,-Field%20of%20view,during%20the%20prime%20Kepler%20mission>

3 Big Questions

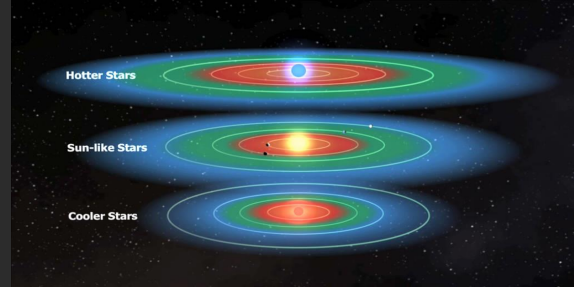
I

Is the Object of Interest an Exoplanet?



II

Is the exoplanet in the habitable zone?



III

Can future observers use our models?



Input values:

Centroid Offset FPF:

Not Transit-Like FPF:

Ephemeris Match Indicates Contamination FPF:

Transit Depth [ppm]:

Stellar Eclipse FPF:

Transit Signal-to-Noise:

Stellar Radius [Solar radii]:

Impact Parameter:

Orbital Period [days]:

Equilibrium Temperature [K]:

Transit Duration [hrs]:

Insolation Flux [Earth flux]:

Transit Epoch [BJD]:

Kepler-band [mag]:

Stellar Surface Gravity [log10(cm/s**2)]:

Stellar Effective Temperature [K]:

Planetary Radius [Earth radii]:

Machine Learning model:

Let's predict!

<https://kepler-groupa.herokuapp.com/>

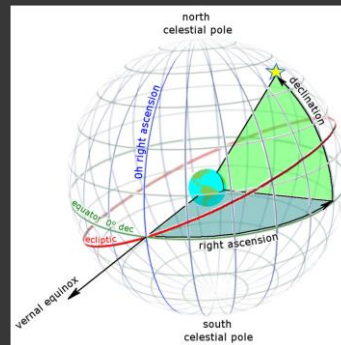
Domain knowledge

CHALLENGES

- Astrophysics terminology
- Cryptic acronyms & abbreviations
 - Koi_tce_delivname, koi_fpflag_nt...
- Dense reference material
 - 382 pages!

**KEPLER
DATA PROCESSING
HANDBOOK
KSCI-19081-003**

CELESTIAL COORDINATES

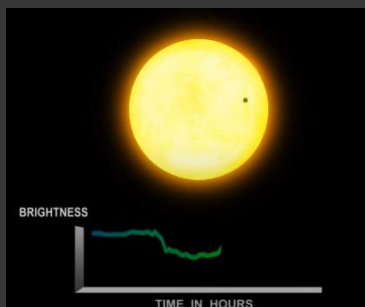


Declination corresponds to latitude & **Right Ascension** to longitude

<https://skyandtelescope.org/astronomy-resources/right-ascension-declination-celestial-coordinates/>

TRANSIT

When one object crosses in front of another in space

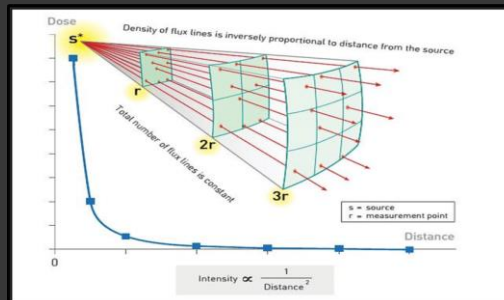


Transits by terrestrial planets produce a small change in a star's brightness of about 1/10,000 (100 parts per million, ppm), lasting for 2 to 16 hours.

<https://exoplanets.nasa.gov/resources/1022/kepler-transit-graph/>

FLUX

A star's apparent brightness



<https://bit.ly/2H8ZvM3>
<https://bit.ly/34yWwNI>

EDA & Preprocessing

Generally clean combination of numerical and categorical

Large number of nulls

Two Ys?!?

Unbalanced



```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 9564 entries, 0 to 9563
Data columns (total 50 columns):
#   Column                Non-Null Count  Dtype
---  -
0   rowid                  9564 non-null   int64
1   kepid                  9564 non-null   int64
2   kepoi_name             9564 non-null   object
3   kepler_name            2294 non-null   object
4   koi_disposition        9564 non-null   object
5   koi_pdposition         9564 non-null   object
6   koi_score              8054 non-null   float64
7   koi_fpflag_nt          9564 non-null   int64
8   koi_fpflag_ss          9564 non-null   int64
9   koi_fpflag_co          9564 non-null   int64
10  koi_fpflag_ec          9564 non-null   int64
11  koi_period              9564 non-null   float64
12  koi_period_err1        9110 non-null   float64
13  koi_period_err2        9110 non-null   float64
14  koi_time0bk            9564 non-null   float64
15  koi_time0bk_err1       9110 non-null   float64
16  koi_time0bk_err2       9110 non-null   float64
17  koi_impact              9201 non-null   float64
18  koi_impact_err1        9110 non-null   float64
19  koi_impact_err2        9110 non-null   float64
20  koi_duration            9564 non-null   float64
21  koi_duration_err1      9110 non-null   float64
22  koi_duration_err2      9110 non-null   float64
23  koi_depth               9201 non-null   float64
24  koi_depth_err1         9110 non-null   float64
25  koi_depth_err2         9110 non-null   float64
26  koi_prad                9201 non-null   float64
27  koi_prad_err1          9201 non-null   float64
28  koi_prad_err2          9201 non-null   float64
29  koi_teq                 9201 non-null   float64
30  koi_teq_err1           0 non-null      float64
31  koi_teq_err2           0 non-null      float64
32  koi_insol               9243 non-null   float64
33  koi_insol_err1         9243 non-null   float64
34  koi_insol_err2         9243 non-null   float64
35  koi_model_snr           9201 non-null   float64
36  koi_tce_plnt_num       9218 non-null   float64
37  koi_tce_delivname       9218 non-null   object
38  koi_steff               9201 non-null   float64
39  koi_steff_err1         9096 non-null   float64
40  koi_steff_err2         9081 non-null   float64
41  koi_slogg               9201 non-null   float64
42  koi_slogg_err1         9096 non-null   float64
43  koi_slogg_err2         9096 non-null   float64
44  koi_srad               9201 non-null   float64
45  koi_srad_err1          9096 non-null   float64
46  koi_srad_err2          9096 non-null   float64
47  ra                      9564 non-null   float64
48  dec                     9564 non-null   float64
49  koi_kepmag             9563 non-null   float64

dtypes: float64(39), int64(6), object(5)
memory usage: 3.6+ MB
```

Handling Null Values

40k+ Null cells across 10k rows & 50 columns of data (500k cells)

363 rows with nulls after cleaning (including dropping +/- error columns)

We decided to drop the nulls due to their small volume & results of imputing

Impute methods evaluated:

```
# Impute NaNs via Mean
```

Mean

```
imputer_mean = SimpleImputer(missing_values=np.nan, strategy='mean')
```

```
keplerProcessed # Impute NaNs via Median
```

Median

```
keplerProcessed imputer_median = SimpleImputer(missing_values=np.nan, strategy='median')
```

```
keplerProcessedMedianImpute_df = keplerProcessed
keplerProcessedMedianImpute_df.iloc[
```

```
# Impute NaNs via Mode
```

Mode

```
imputer_mode = SimpleImputer(missing_values=np.nan, strategy='most_frequent')
```

```
keplerProcessedModeImpute_df = keplerProcessed_df.copy(deep=True)
```

```
keplerProcessedModeImpute_df.iloc[:, :] = imputer_mode.fit_transform(keplerProcessedMeanImpute_df)
```

Mode had a negative f1 impact while Mean & Median had no discernable impact

```
keplerRAW_df.isnull().sum().sum()
```

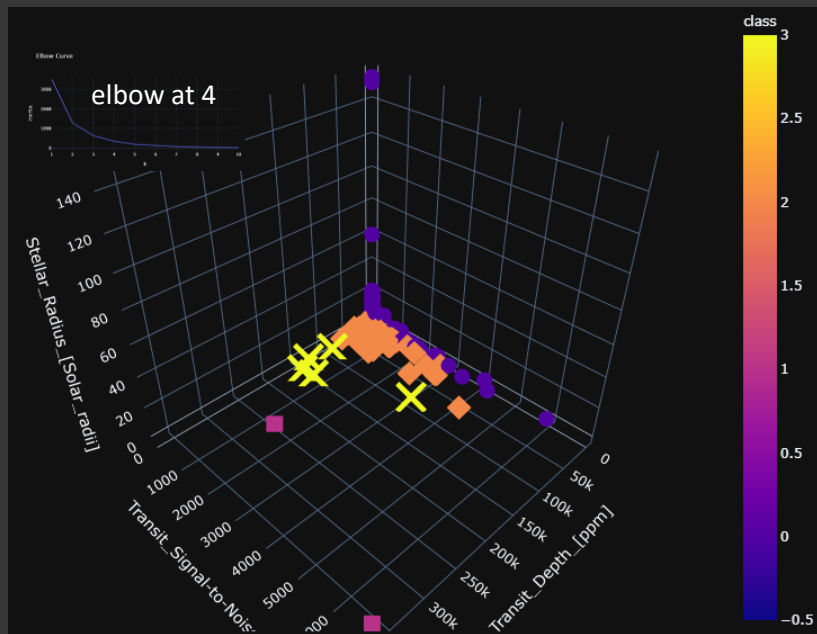
40557

```
keplerProcessed_df.isnull().sum().sum()
```

3572

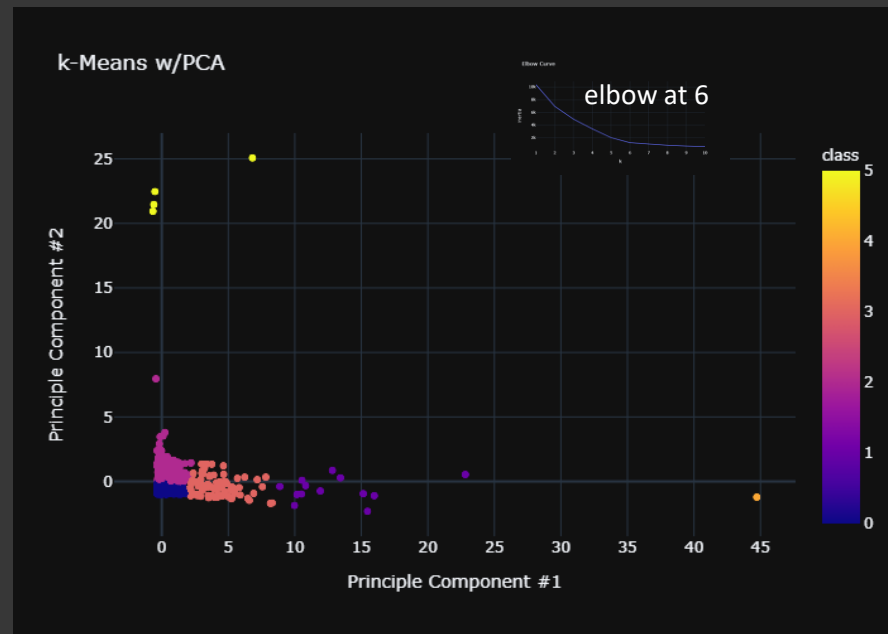
```
Exoplanet_Archive_Disposition      0
Not_Transit-Like_FPF               0
Stellar_Eclipse_FPF               0
Centroid_Offset_FPF               0
Ephemeris_Match_Indicates_Contamination_FPF  0
Orbital_Period_[days]             0
Transit_Epoch_[BJD]               0
Impact_Parameter                  363
Transit_Duration_[hrs]            0
Transit_Depth_[ppm]              363
Planetary_Radius_[Earth_radii]    363
Equilibrium_Temperature_[K]      363
Insolation_Flux_[Earth_flux]     321
Transit_Signal-to-Noise          363
TCE_Planet_Number                 346
koi_steff                        363
koi_slogg                       363
koi_srad                        363
right_ascension                  0
declination                      0
Kepler_band_[mag]                1
TCE_Delivery_q1_q16_tce          0
TCE_Delivery_q1_q17_dr24_tce     0
TCE_Delivery_q1_q17_dr25_tce     0
dtype: int64
```

k-Means Clustering



For the three most important features, most objects have:

- transit depth <20,000 parts/million
- transit signal-to-lose <2000
- stellar radius <20 solar radii

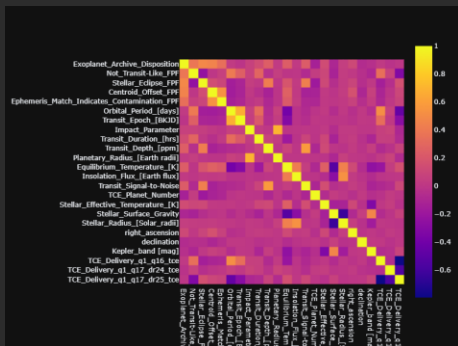


- 36% of the information is lost reducing four dimensions to two
- Confirmation that most of the data is consistent/homogeneous

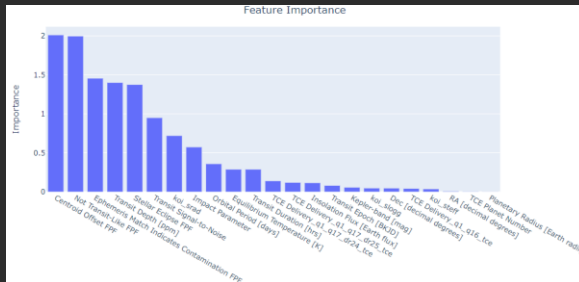
Feature Analysis & A Tale of Two Ys

- **Which target?** Kepler Disposition vs Exoplanet Archive Disposition (EAD)
 - We chose EAD as it was the result of the most recent NASA analysis
 - ML models had a 99% f1 with kepler disposition
- **We analyzed our features using the methods below**
 - "Sequential Feature Selection" is part of the mlxtend library - programmatically analyzes feature combinations

Correlation Matrix



Coefficient Graph



Sequential Feature Selection

```
8: {'feature_idx': (0, 1, 2, 3, 9, 20, 21, 22),
'cv_scores': array([-0.01962382, -0.01745037, -0.00757576, -0.00960293, -0.00605649,
-0.01017782, -0.01898536, -0.01070084, -0.00808577, -0.00282427]),
'avg_score': -0.011108341749627281,
'feature_names': ('koi_fpflag_nt',
'koi_fpflag_ss',
'koi_fpflag_co',
'koi_fpflag_ec',
'koi_prad',
'koi_tce_delivname_q1_q16_tce',
'koi_tce_delivname_q1_q17_dr24_tce',
'koi_tce_delivname_q1_q17_dr25_tce')},
```

Future options

- Variance Inflation Factor
- Multicollinearity
- Lasso regression

Supervised Machine Learning

LOGISTIC REGRESSION- 83% f1

- Chosen since our questions are categorical
- Weaker results likely due to unbalanced data

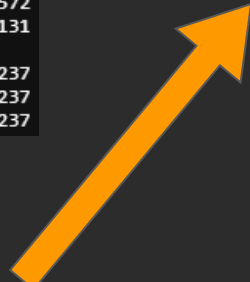
	precision	recall	f1-score	support
0	0.68	0.57	0.62	534
1	0.66	0.74	0.69	572
2	0.98	1.00	0.99	1131
accuracy			0.83	2237
macro avg	0.77	0.77	0.77	2237
weighted avg	0.83	0.83	0.83	2237



GRADIENT BOOSTED TREES- 90% f1

- Chosen to better handle the data imbalance

	precision	recall	f1-score	support
0	0.82	0.78	0.80	534
1	0.81	0.83	0.82	572
2	0.98	1.00	0.99	1131
accuracy			0.90	2237
macro avg	0.87	0.87	0.87	2237
weighted avg	0.90	0.90	0.90	2237



RANDOM FOREST- 90% f1

- Alternative to better handle the data imbalance

	pre	rec	spe	f1	geo	iba	sup
0	0.81	0.78	0.94	0.79	0.86	0.72	534
1	0.82	0.81	0.94	0.81	0.87	0.75	572
2	0.98	1.00	0.98	0.99	0.99	0.98	1131
avg / total	0.90	0.90	0.96	0.90	0.93	0.86	2237

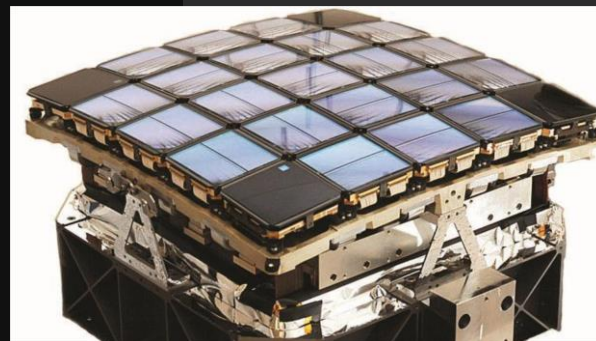
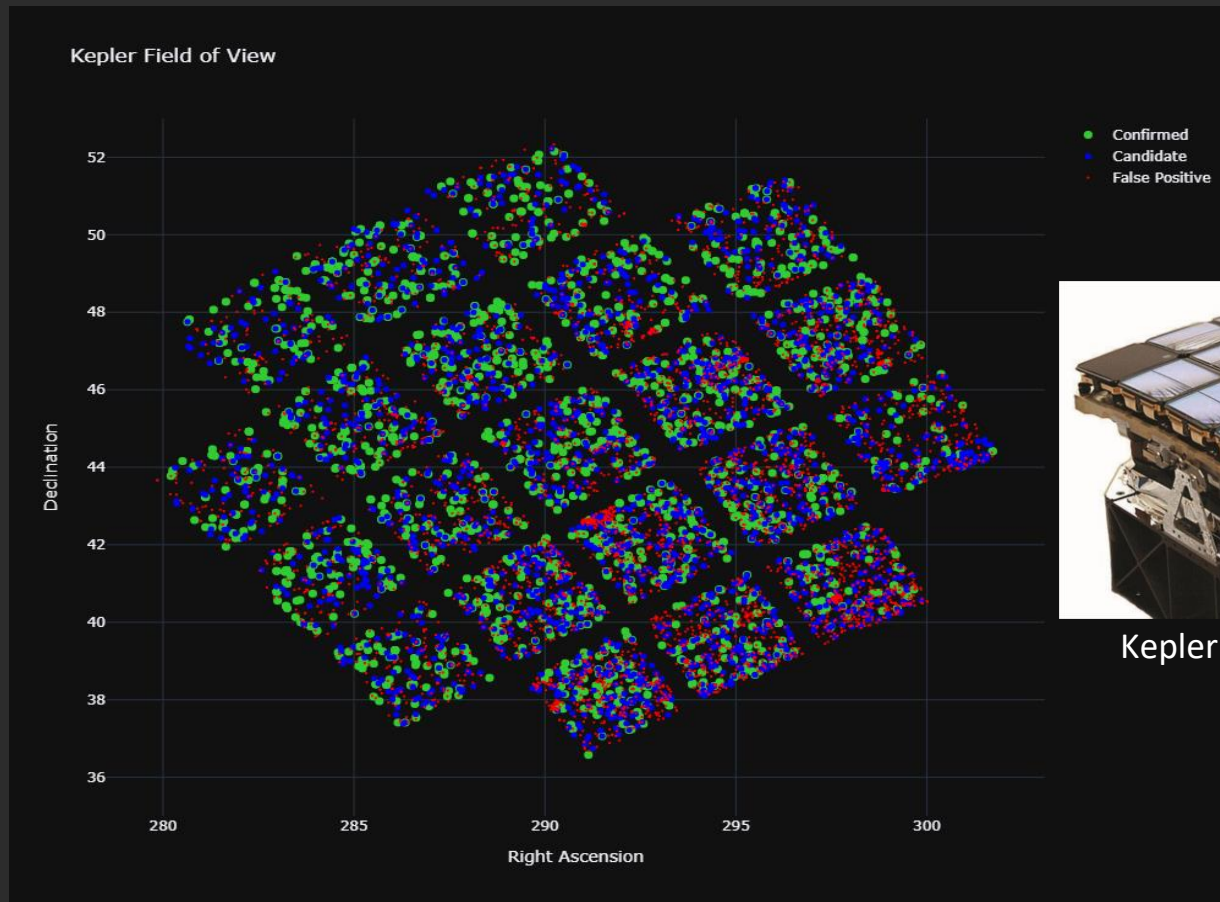


DEEP NEURAL NETWORK- 84% f1

- Uses relu and softmax

	precision	recall	f1-score	support
0	0.67	0.70	0.69	534
1	0.71	0.68	0.70	572
2	0.98	0.99	0.98	1131
accuracy			0.84	2237
macro avg	0.79	0.79	0.79	2237
weighted avg	0.84	0.84	0.84	2237

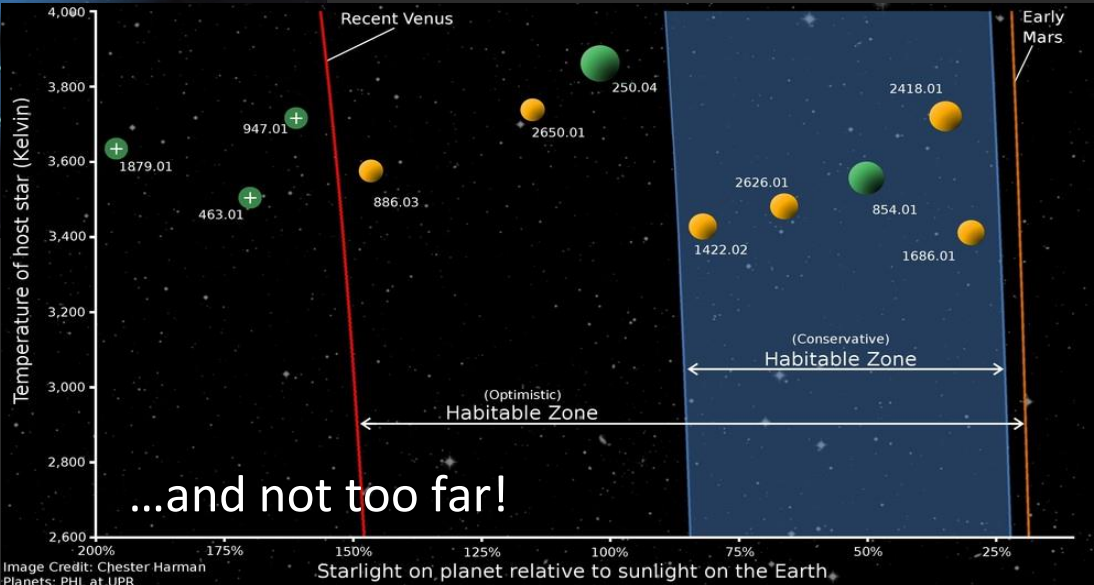
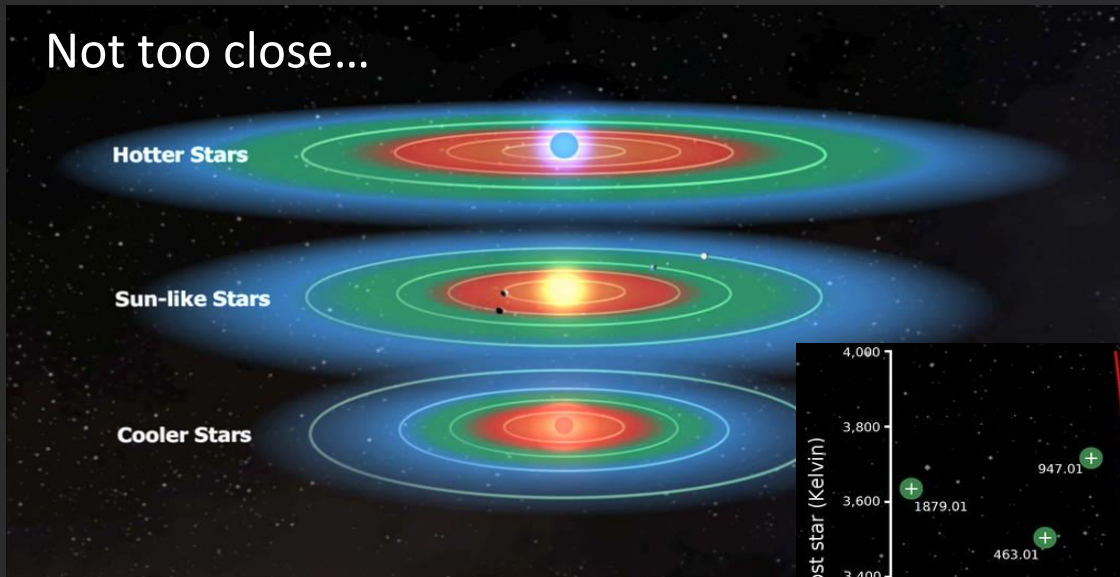
Graphing the results



Kepler Telescope's Photometer

Habitable or Not? The Goldilocks Zone

Not too close...



Is the Exoplanet in the Goldilocks Zone?

Habitable Criteria:

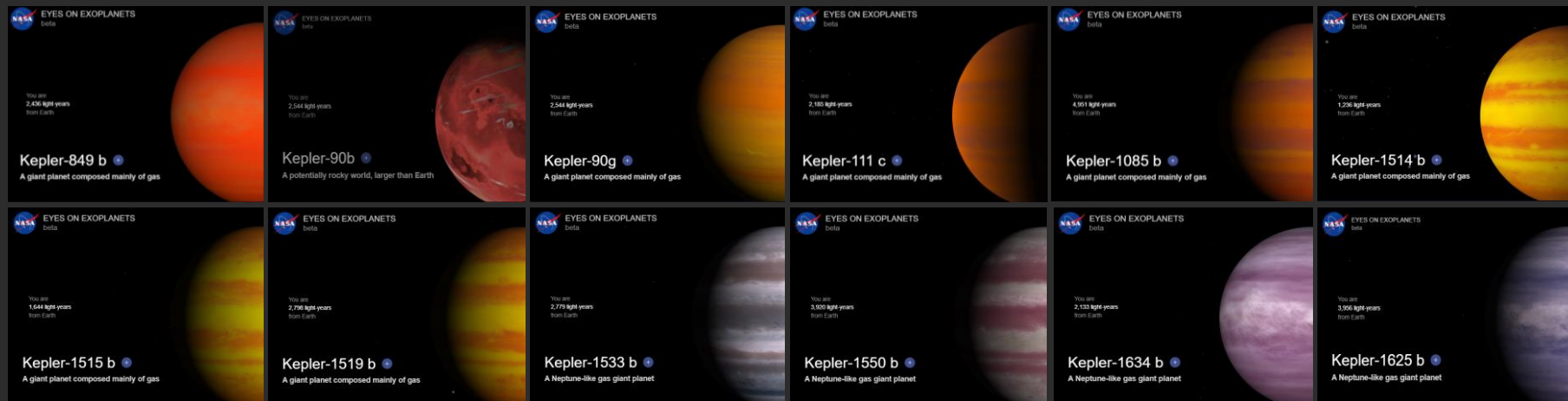
- `Orbital_period[days]: 200 ~ 400`
- `Stellar_effective_temperature: > 5500 ~ 6500`
- `Stellar_radius[solar_radii]: 1 ~ 2`
- `Stellar_surface_gravity[log10(cm/s**2)]: > 4`
- `Stellar_metallicity: > 0`

Confirmed Exoplanets: **2293**

Habitable Zone: **12**

Candidate Objects: **2248**

Habitable Zone: **37**



Prediction web-app

Takes new observations and predicts if the object is an exoplanet using our ML models

- Built with ES6/HTML
- Hosted online

<https://kepler-groupa.herokuapp.com/>



Input values:

Centroid Offset FPP: 0

Not Transit-Like FPP: 0

Ephemeris Match Indicates Contamination FPP: 0

Transit Depth [ppm]: 1517.5

Stellar Eclipse FPP: 0

Transit Signal-to-Noise: 66.5

Stellar Radius [Solar radii]: 0.972

Impact Parameter: 0.538

Orbital Period [days]: 11.09432054

Equilibrium Temperature [K]: 835

Transit Duration [hrs]: 4.5945

Insolation Flux [Earth flux]: 114.81

Transit Epoch [BJD_T]: 171.20116

Kepler-band [mag]: 15.714

Stellar Surface Gravity [log10(cm/s**2)]: 4.486

Stellar Effective Temperature [K]: 6046

Planetary Radius [Earth radii]: 3.9

Machine Learning model: Supervised ML logistic Regression

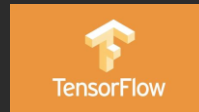
Let's predict!

Centroid Offset FPP: 0 | Not Transit-Like FPP: 0 | Ephemeris Match Indicates Contamination FPP: 0 | Transit Depth [ppm]: 1517.5 | Stellar Eclipse FPP: 0 | Transit Signal-to-Noise: 66.5 | Stellar Radius [Solar radii]: 0.972 | Impact Parameter: 0.538 | Orbital Period [days]: 11.09432054 | Equilibrium Temperature [K]: 835 | Transit Duration [hrs]: 4.5945 | Insolation Flux [Earth flux]: 114.81 | Transit Epoch [BJD_T]: 171.20116 | Kepler-band [mag]: 15.714 | Stellar Surface Gravity [log10(cm/s**2)]: 4.486 | Stellar Effective Temperature [K]: 6046 | Planetary Radius [Earth radii]: 3.9 | Machine Learning model chosen: Supervised ML logistic Regression

Exoplanet predicted!!!



Technologies



kaggle



APPENDIX

Fork Scope

BACK-END updates

EXPLORATORY DATA ANALYSIS

- ✓ Handling nulls
- ✓ Cluster analysis - *in progress*
- ✓ Visualizations

MACHINE LEARNING MODELS

- ✓ Baseline
- Feature selection
- Tuning - *in progress*

PREPROCESSING

- Feature reduction
- ✓ Conversion to numeric
- ✓ Scaling

HABITABLE ZONE ANALYSIS

- ✓ Filtering Model results

FRONT-END updates

PRESENTATION

WEB APP

- Hosted on Heroko - *in progress*