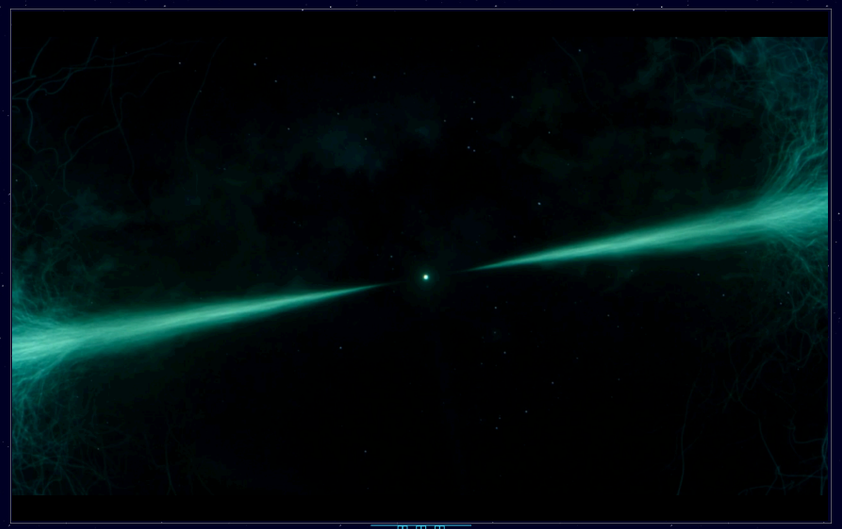

PULSARS
Detecting Dead Stars in Deep Space
Presentation by **Ru Keïn** | February 2020

WHAT IS A PULSAR?

Cosmos: A Spacetime Odyssey, Season 1 Episode 13, “Unafraid of the Dark” (See appendix)

When a massive star dies…it blows its guts into space. We call these “neutron stars” because they consist almost entirely of subatomic particles called neutrons,

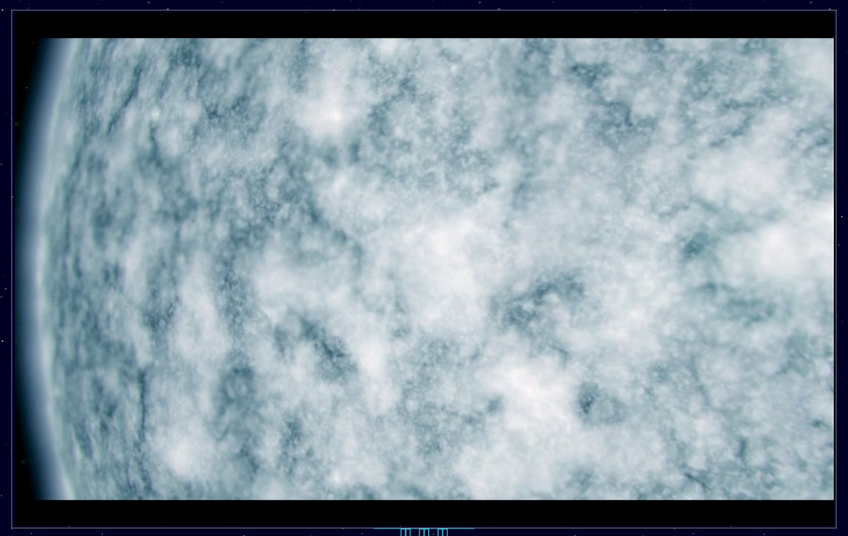
WHAT IS A PULSAR?



Cosmos: A Spacetime Odyssey, Season 1 Episode 13, “Unafraid of the Dark” (See appendix)

A rare type of neutron star is called a “pulsar” which produces radio emissions detectable here on Earth.

WHAT IS A PULSAR?



Cosmos: A Spacetime Odyssey, Season 1 Episode 13, “Unafraid of the Dark” (See appendix)

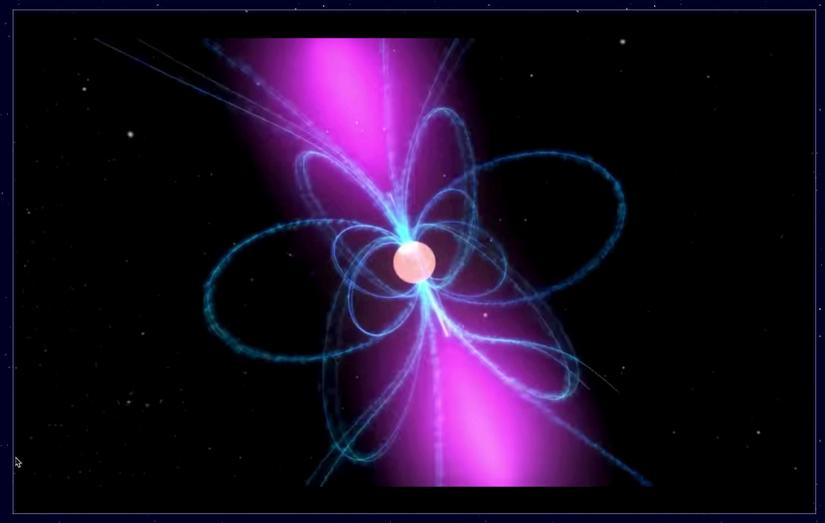
When a star becomes a neutron star, it shrinks from a million miles across to only TEN. The ‘corpse’ is so dense that a single grain of it weighs as much as the Great Pyramid in Egypt.

WHAT IS A PULSAR?

- Source: What is a Pulsar? (NASA) https://www.youtube.com/watch?v=gjLk_72V9Bw

They seem to wink on and off at regular intervals like a lighthouse when viewed from a distance. Pulsars emit continuous beams of radiation that sweep through Earth's line of sight.

WHAT IS A PULSAR?

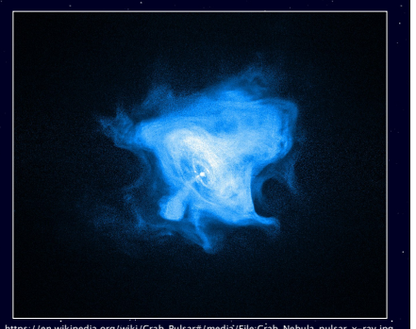


- Source: What is a Pulsar? (NASA) https://www.youtube.com/watch?v=gjLk_72V9Bw

Pulsars accelerate particles to tremendous energies in their magnetospheres. In this video, gamma rays are shown in magenta. The "pulses" of high-energy radiation we see from a pulsar are due to a misalignment of the neutron star's rotation axis and its magnetic axis.

http://hubblesite.org/newscenter/newsdesk/archive/releases/2002/24/image/a

https://en.wikipedia.org/wiki/Crab_Pulsar#/media/File:Crab_Lucky_video2.gif21



https://en.wikipedia.org/wiki/Crab_Pulsar#/media/File:Crab_Nebula_pulsar_x-ray.jpg

CRAB NEBULA PULSAR

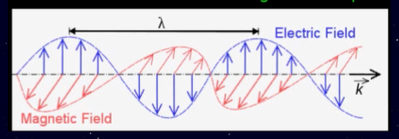
A few years after the discovery of pulsars by radio astronomers, the Crab and Vela pulsars were detected at gamma-ray energies.

The Crab pulsar (found in the Crab Nebula) is one of the brightest gamma-ray sources in the sky.

https://fermi.gsfc.nasa.gov/inc/img/spacecraft.jpg

Image Credit: NRAO/AUI

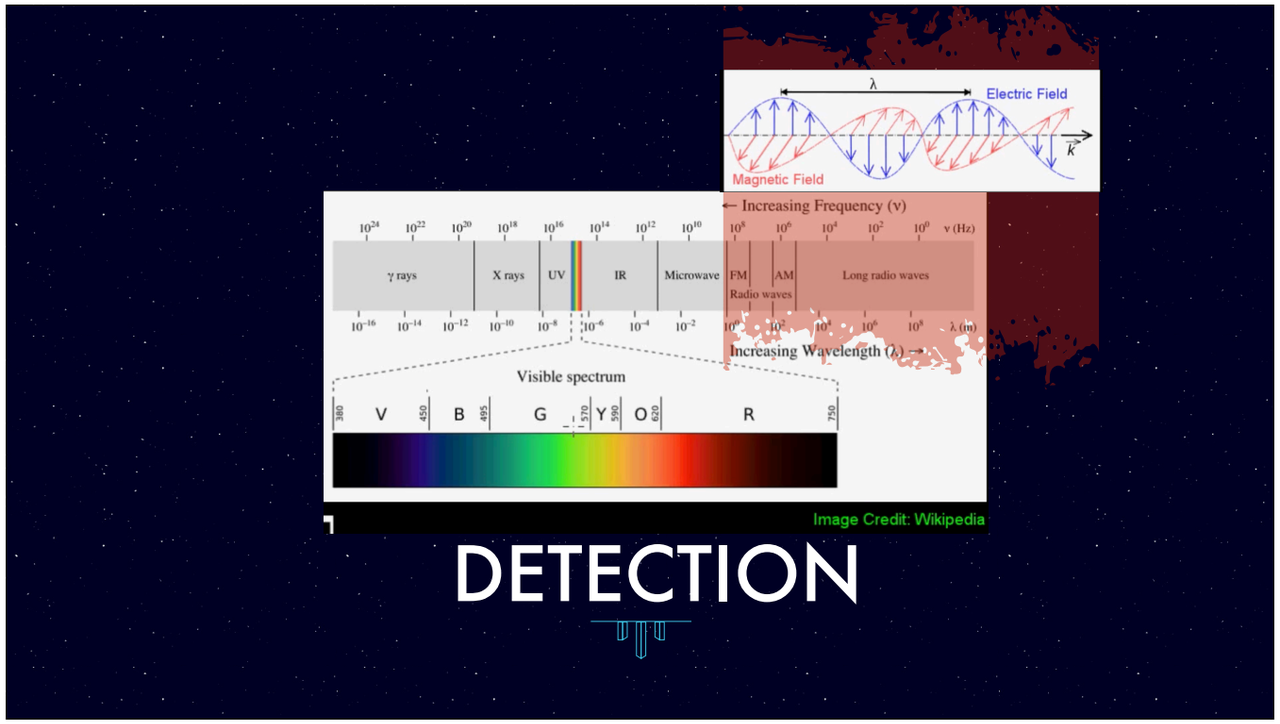
Image Credit: Wikipedia



DETECTION

NASA's Fermi Gamma-ray Space Telescope

As pulsars rotate, their emission beam sweeps across the sky, and when this crosses our line of sight, produces a detectable pattern of broadband radio emission. As pulsars rotate rapidly, this pattern repeats periodically. Pulsar search involves looking for periodic radio signals with large radio telescopes.

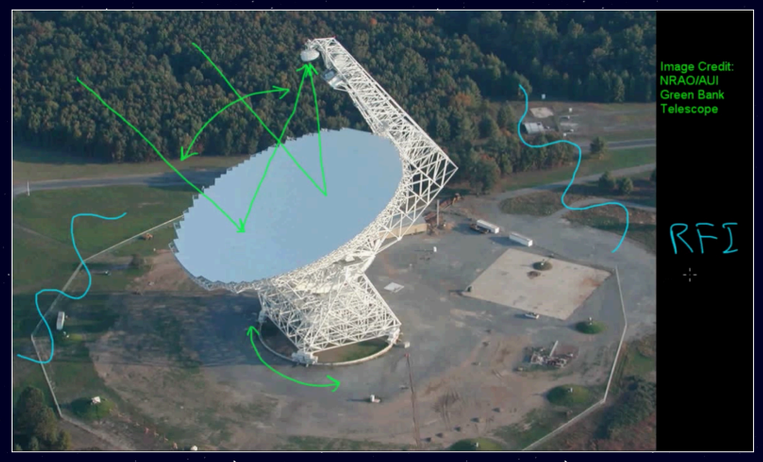


DETECTION

Each pulsar produces a slightly different emission pattern, which varies slightly with each rotation. Thus a potential signal detection known as a 'candidate', is averaged over many rotations of the pulsar, as determined by the length of an observation.

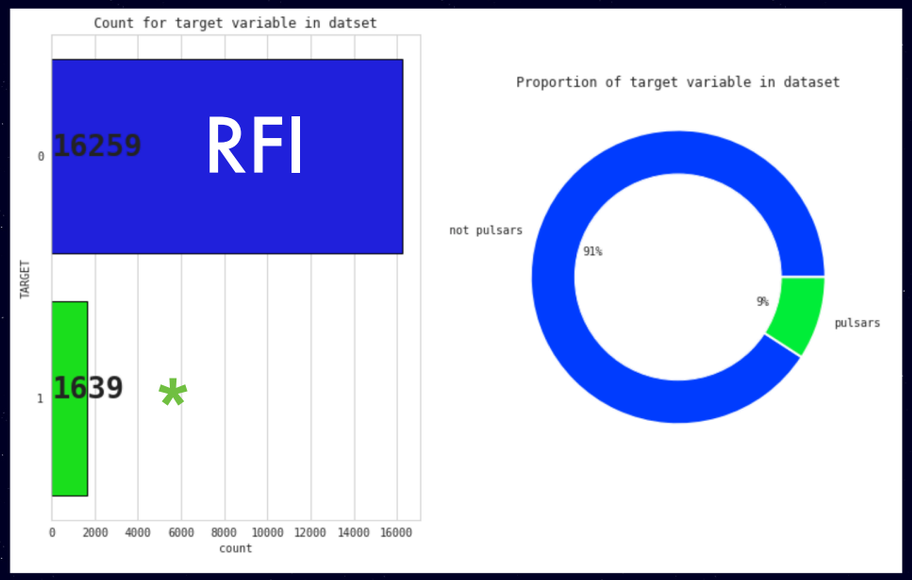
RFI

- **LOTS OF NOISE** Radio frequency interference (RFI) makes analysis very difficult.



In the absence of additional info, each candidate could potentially describe a real pulsar. However in practice almost all detections are caused by radio frequency interference (RFI) and noise, making legitimate signals hard to find.

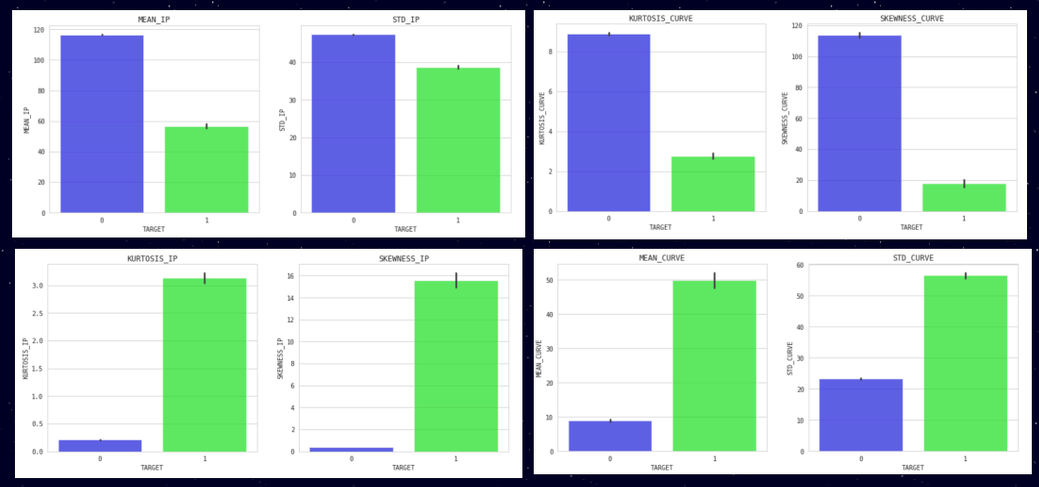
LISTENING FOR A WHISPER IN A NOISY ROOM



- **17,898** total examples:
- **16,259** spurious examples caused by RFI/noise
- **1,639** real pulsar examples.

What this means for our dataset of almost 18,000 samples is that only 9% of them are going to be actual pulsars, and the rest is noise. In other words, it’s like listening for a whisper in a room of people talking loudly.

WHAT ARE WE *REALLY* LOOKING FOR?

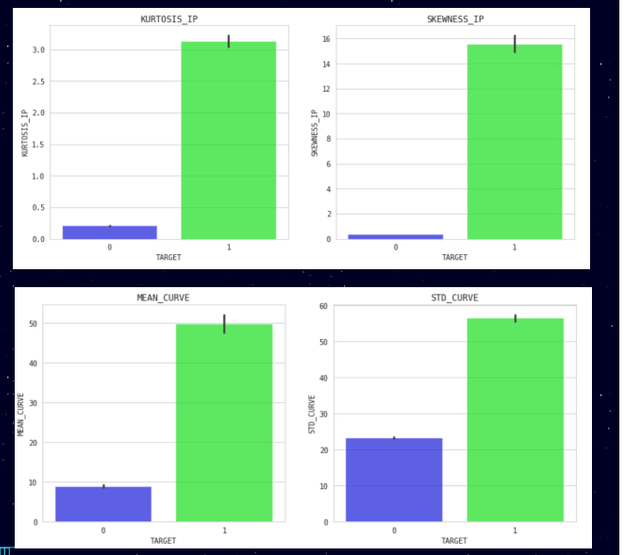


Data scientists are interested in something called “feature importance” - it means out of all the things I can analyze, which ones are the best at predicting an outcome?

RADIO WAVE SIGNALS WITH:

HIGH:

* Kurtosis Integrated Profile
* Skewness Integrated Profile
* Mean DM-SNR Curve
* Standard Deviation DM_SNR Curve



For this dataset, we could try classifying pulsars vs noise by looking for radio waves that show: Higher values in kurtosis_ip, skewness_ip, mean_curve, Std_curve.

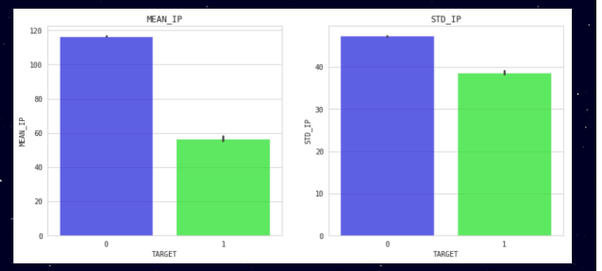
RADIO WAVE SIGNALS WITH:

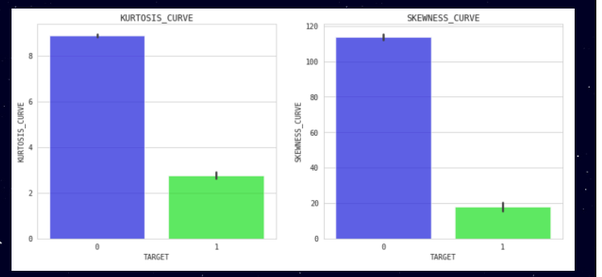
LOW:

* Mean Integrated Profile
* Kurtosis DM-SNR Curve
* Skewness DM-SNR Curve

Lower:

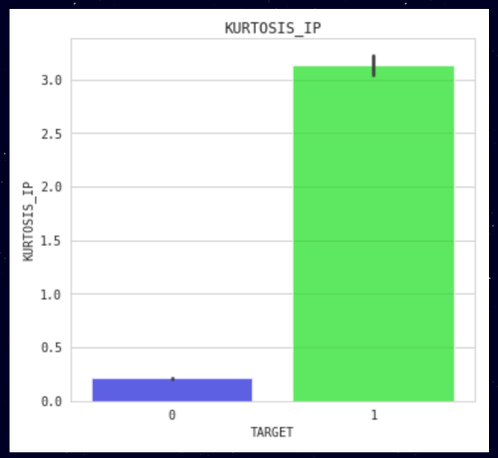
* *Standard Deviation Integrated Profile*



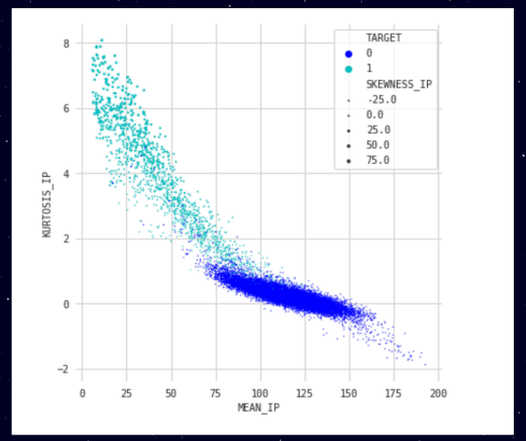


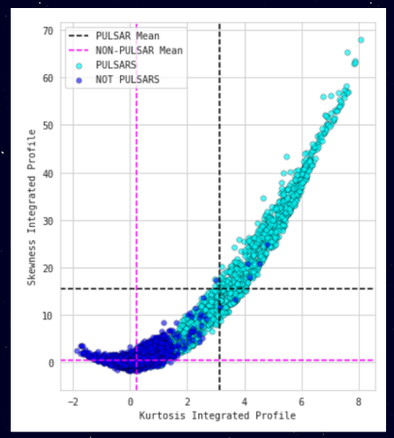
For this dataset, we could try classifying pulsars vs noise by looking for radio waves that show: Higher values in kurtosis_ip, skewness_ip, mean_curve, Std_curve.

BEST PREDICTOR OF PULSARS

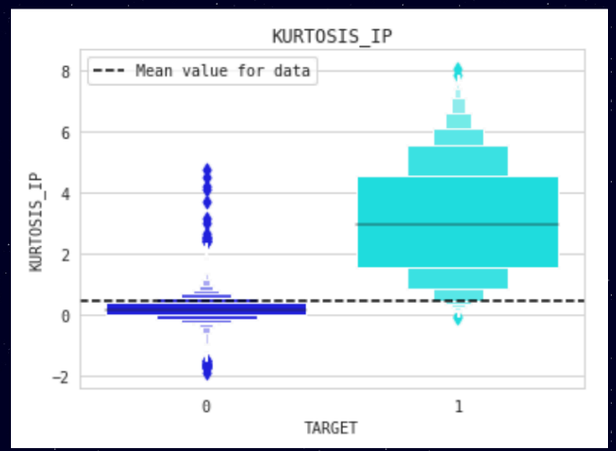


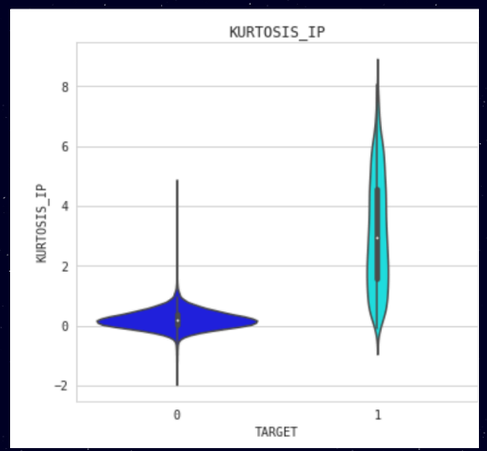
MOST Important features for this dataset: Lowest values in kurtosis_ip and skewness_ip (NOTE this data is normalized)





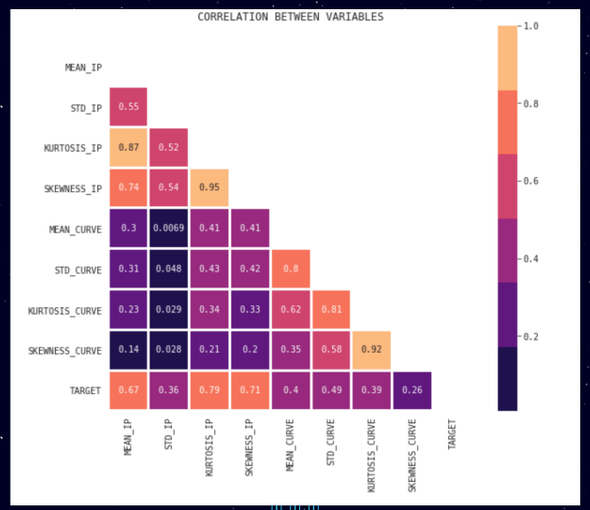
PULSARS VS NOISE

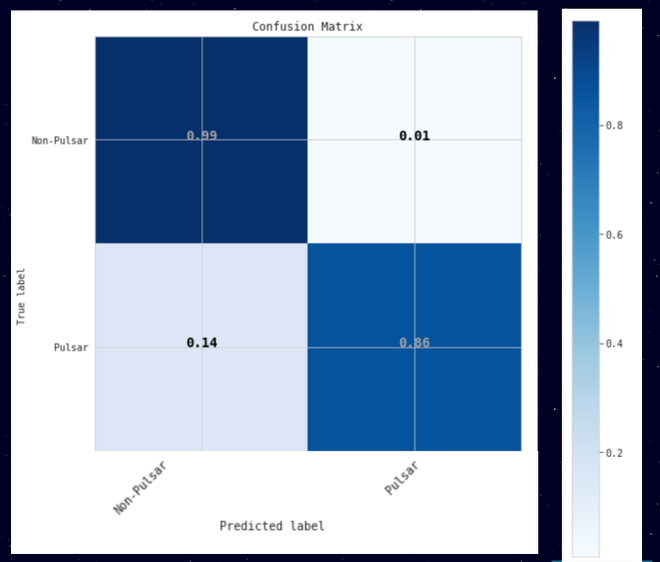




PULSARS VS NOISE

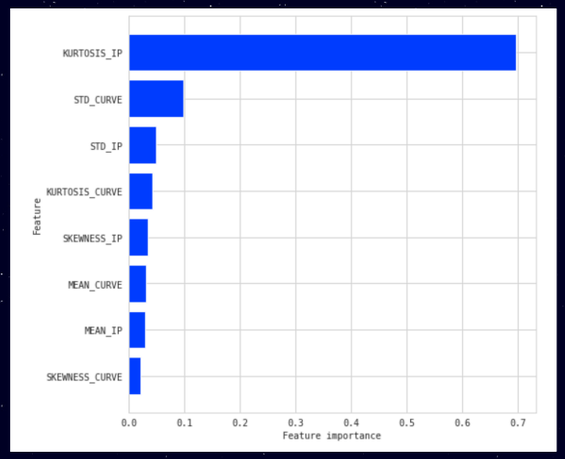
FEATURE CORRELATION





RESULTS

- The model correctly classified 99% of the non-pulsar signals as RFI/ noise, mistaking only 1% of the data as pulsars when it was in fact only RFI/Noise.
- The model correctly classified 86% of the pulsars as pulsars, mistaking 14% as noise when they were actually pulsars.
- 466 Pulsars correctly identified
- 78 pulsars misclassified as noise



RECOMMENDATIONS

1. Focus on Kurtosis Integrated Profile
2. Focus on Standard Deviation DM-NSR Curve
3. Closer analysis of what this means and if other celestial objects producing cosmic rays show the same attributes.

Kurtosis: the shape of a distribution's tails in relation to its overall shape.Kurtosis is a statistical measure used to describe the degree to which scores cluster in the tails or the peak of a frequency distribution. The peak is the tallest part of the distribution, and the tails are the ends of the distribution.

There are three types of kurtosis: mesokurtic, leptokurtic, and platykurtic.

Mesokurtic: Distributions that are moderate in breadth and curves with a medium peaked height.
Leptokurtic: More values in the distribution tails and more values close to the mean (i.e. sharply peaked with heavy tails)
Platykurtic: Fewer values in the tails and fewer values close to the mean (i.e. the curve has a flat peak and has more dispersed scores with lighter tails).

FUTURE WORK

Improving the model, trying other ways of scaling, balancing class weights.

Looking at stars right before they die - predicting whether or not it will become a pulsar or not (could be slightly impossible considering stars live for billions of years…)

Pulsars are of considerable scientific interest as probes of space-time, the inter-stellar medium, and states of matter. Future work would consist of:
1. improving the model, trying other ways of scaling, balancing class weights
2. conducting research on larger datasets of pulsars
3. looking at stars right before they die - predicting whether or not it will become a pulsar or not (could be slightly impossible considering stars live for billions of years…)


THANK YOU

APPENDIX

VIDEOS:

- What is a Pulsar? (NASA) https://www.youtube.com/watch?v=gjLk_72V9Bw
- Observing Pulsars with Radio Telescopes https://www.youtube.com/watch?v=AVGNWfKP9VM
- Cosmos: A Spacetime Odyssey, Season 1 Episode 13, "Unafraid of the Dark" https://www.amazon.com/Cosmos-Spacetime-Odyssey-Season-1/dp/B00IJL0CB4

IMAGES:

- http://hubblesite.org/newscenter/newsdesk/archive/releases/2002/24/image/a
- https://en.wikipedia.org/wiki/Crab_Pulsar#/media/File:Crab_Nebula_pulsar_x-ray.jpg
- https://en.wikipedia.org/wiki/Crab_Pulsar#/media/File:Crab_Lucky_video2.gif21
- https://fermi.gsfc.nasa.gov/inc/img/spacecraft.jpg