Science AMA Series: We're planet hunters from NASA, Google AI, and The University of Texas, Austin. Ask us anything!

NASAKepler [1] and r/Science AMAs[1]

[1]Affiliation not available

April 17, 2023

Abstract

Ask us about NASA's planet-hunting Kepler space telescope's latest discovery, which was made using machine learning from Google. Machine learning is an approach to artificial intelligence, and demonstrates new ways of analyzing Kepler data. Please post your questions here. We'll be online from 12:00-1:30 pm PT (3:00-4:30 pm ET, 20:00-21:30 UTC), and will sign our answers. Ask us anything! Paul Hertz, Astrophysics Division director at NASA Headquarters in Washington Christopher Shallue, senior software engineer at Google AI in Mountain View, California Andrew Vanderburg, astronomer and NASA Sagan Postdoctoral Fellow at The University of Texas, Austin Jessie Dotson, Kepler project scientist at NASA's Ames Research Center in California's Silicon Valley Kartik Sheth, program scientist, Astrophysics Division at NASA Headquarters in Washington UPDATE (10:44 am PT): Today, December 14, 2017, researchers announced our solar system now is tied for most number of planets around a single star, with the recent discovery of an eighth planet circling Kepler-90, a Sun-like star 2,545 light years from Earth. The planet was discovered in data from NASA's Kepler space telescope. For more info about the discovery, visit https://www.nasa.gov/press-release/artificial-intelligence-and-nasa-data-used-to-discover-eighth-planet-circling-distant The newly-discovered Kepler-90i –a sizzling hot, rocky planet that orbits its star once every 14.4 days – was found using machine learning from Google. Machine learning is an approach to artificial intelligence in which computers "learn." In this case, computers learned to identify planets by finding in Kepler data instances where the telescope recorded signals from planets beyond our solar system, known as exoplanets. The discovery came about after researchers Andrew Vanderburg and Christopher Shallue trained a computer to learn how to identify exoplanets in the light readings recorded by Kepler – the miniscule change in brightness captured when a planet passed in front of, or transited, a star. Inspired by the way neurons connect in the human brain, this artificial "neural network" sifted through Kepler data and found weak transit signals from a previously-missed eighth planet orbiting Kepler-90, in the constellation Draco. We'll be back to answer your questions at 12 pm PT. Ask us anything! UPDATE (1:40 pm PT): That's all the time we have for today. Thanks for joining us. To learn more about NASA's planet-hunting Kepler spacecraft, visit www.nasa.gov/kepler. Follow us on social media at https://twitter.com/nasakepler and https://www.facebook.com/NASAsKeplerMission/. Proof: https://twitter.com/NASAKepler/status/941406190046552065

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NASAKEPLER R/SCIENCE

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Please post your questions here. We'll be online from 12:00-1:30 pm PT (3:00-4:30 pm ET, 20:00-21:30 UTC), and will sign our answers. Ask us anything!
Paul Hertz, Astrophysics Division director at NASA Headquarters in Washington
Christopher Shallue, senior software engineer at Google AI in Mountain View, California
Andrew Vanderburg, astronomer and NASA Sagan Postdoctoral Fellow at The University of Texas, Austin
Jessie Dotson, Kepler project scientist at NASA's Ames Research Center in California's Silicon Valley
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Proof: https://twitter.com/NASAKepler/status/941406190046552065

CORRESPONDENCE:

DATE RECEIVED:
December 15, 2017

DOI:
10.15200/winn.151325.59467

My students want to know how long it would take to get to the nearest planet outside of our solar system?

Sent from Coral Academy of Science in Las Vegas from Mr. Shiver's 4th Grade Classroom

Coralacademylshiver

Hi Mr Shiver's 4th graders! Great question. The nearest known planet outside our solar system is 4.2

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light years away. So, even if you could travel as fast as light, it would take you 4.2 years to get there. Of course, we can't travel anywhere near the speed of light. Today, we are pretty good at finding planets outside our solar system, but we have a *lot* of work to do to figure out how to visit to one of them. Maybe one of yall can figure that out for us when you grow up! -Jessie Dotson, NASA Ames Research Center

I was underwhelmed when I heard 2 planets were discovered. But I could be unaware of the complexity, or lack of time, looking for exoplanets, and I guess I am spoiled with over 1000+ exoplanet discoveries at this point. Anyway...

How long did it take to confirm these 2 planets and how long did that take compared to non-AI methods?

How efficient do you see this method in the future? Will the AI learn to make identifications thus going more quickly?

How much will this method need to be adapted to future planet hunting telescopes?

Sorry for all the questions, I only had time to listen to a brief part of the livestream. I took a Astrobiology class as an undergrad at Penn State with Dr. Chris House and loved the exoplanet part. Thanks for helping to make scientific discoveries!

[CaptainBrant]()

These planets were not particularly difficult to confirm, once we had identified the signals. The challenge with these two discoveries was actually finding the signals, which took months. Total, our work on this probably took about 9 months. I started working with Chris on this project about a year ago, and we submitted the paper in September.

We definitely have plans to keep working on this method. There are clear areas where it struggles, and have ideas how to make it better. We hope that eventually we'll be able to use this to search the entire Kepler dataset.

It shouldn't be too difficult to adapt the work here to future telescopes like TESS - it will just be a matter of building a new training set to help the neural network adapt to the unique characteristics of TESS data. Andrew V (UT Austin)

I thought of another question: What's your take on Planet Nine? Could machine learning help in the search for it (if it's out there)?

Could machine learning help with other astronomical or cosmological discoveries?

Thank you!

[kiri-kin-tha]()

Machine learning could definitely help the search for planet 9, and likely already is. In fact, one of the first big successes for machine learning in astronomy is identifying moving things in the sky, or things that suddenly appear or disappear (see https://arxiv.org/abs/1501.05470). Recently have been other papers using machine learning in all other sorts of areas of astronomy: https://arxiv.org/abs/1711.03121

My personal take (not the view of NASA) on planet 9 is that the evidence for it is compelling, but given the hundreds of years of history of claimed additional planets in the solar system based on dynamics, it's not a slam dunk, and I won't really believe it until I see a picture of it. Andrew V (UT Austin)

Could you share any nuance of planet hunting? Something that isn't typically described in popular science articles about how exoplanets are found and characterised but surfaces and gives a some pain once you start in the field yourself.

TheBionicAndroid

One of the things I didn't know when I started searching for planets is how many false positives there are. In the press, usually the focus is on the succeses, the new planets etc. But when I was first starting out, the first 5 or 10 possible planets I saw were false positives. Eventually I learned the subtle characteristics that distinguish real planets and got better at it, but sorting out the false positives from the true planets is always a crucial part of the story. -- Andrew V (UT Austin)

Could you share any nuance of planet hunting? Something that isn't typically described in popular science articles about how exoplanets are found and characterised but surfaces and gives a some pain once you start in the field yourself.

TheBionicAndroid

I have a background in computer science and machine learning, but I didn't have any experience with exoplanet hunting before this project. I had to learn how to distinguish actual planet signals from signals caused by other objects -- just like our model! I learned that there are many other objects that can cause signals that look a lot like planets, such as starspots and binary stars. - Chris Shallue, Google AI

Hi, I loved the talk, thankyou! I have started to read the published paper and am trying to understand how you processed the data. Were the training, validation and test sets actually a manually selected set of transit events, collapsed to light curves? If so, does this mean a human must always pre-select the locations to study beforehand and the network is just a classifier that says "yes or no, this is a planet"? With that in mind, can the network be modified to take a very large image from hubble and find the transit events itself, or can the model only work with the flattened 1x201 / 1x2001 inputs?

TheRealWireline

The training, validation, and test sets came from the existing Kepler planet catalog (https://exoplanetarchive.ipac.caltech.edu/cgi-bin/TblView/nph-tblView?app=ExoTbls&config=q1_q17_dr24_tce) which has labeled some of the signals as planet candidates, false positives, or nontransiting phenomena (click on "Select columns") and "Autovetter training set label". These signals were carefully vetted by humans. In the future, we're looking into simulating our training data so that we are sure that the training data is accuately labeled and so that we can produce much much more training data.

It should definitely be possible to apply this method to other telescopes - the 201 and 2001 length vectors were fairly arbitrary choices. The technique is very flexible! Andrew V, UT Austin

What kind of neural network was applied for this task? Was it RNN?

Were you using TensorFlow and Keras?

Did you use some data generator for training your model? Previous works that I am aware of were complaining about too small datasets and they partially generated their own random data based on transit models.

Did you use only Kepler data, or some other datasources too, like HatNet?

custom_user

We used a convolutional neural network which is the same kind of neural network we typically use to classify objects in images (like in Google Photos). It might be possible to use an RNN for this task, although these light curves are very long, with thousands of data points, and RNNs sometimes have trouble learning long-term dependencies. I also found it much slower to train an RNN than a convolutional neural network on this task. I'd love to see someone make it work, though!

We were using TensorFlow, but we didn't use the Keras library for this project. We plan to release all the code for training our neural network - stay tuned!

We only used data from the Kepler space telescope.

-Chris Shallue, Google AI

Hello, You began to use machine learning to identify exoplanets. My question is, are you able to state the probability of error when using such systems? For me it seems that such systems are often "magic" blackboxes with incredible results. But doesn't the scientific value suffer from such systems when you are not knowing how good the routines in it really are?

Urben1680

When we develop machine learning models, we typically hold out some fraction of our labeled training data -- say 10% -- that we do not show our model during the training process. Then, when our model has finished training, we use that 10% of data to test the performance of our model on data it has never seen before. In this case, we found that our model was 96% accurate on 10% of our training set that we held out for testing purposes.

In terms of understanding our machine learning systems, we do have some techniques that we use to "look inside" our models and to help understand why they make certain decisions. In this case, we developed a few ways to visualize the way our neural network was making sense of the Kepler signals. Check out Pages 8 and 9 of our research paper.

In general, neural networks are not inherently uninterpretable, and there is entire field of research working on further developing the tools to probe and understand them. We are making progress, for example designing transparent machine learning Gupta et al. JMLR 2016, Gupta et al. NIPS 2016, visualizing what an ML system is learning "interlingua" in multi-lingual neural translation, Smilkov et al., 2016 and more. - Chris Shallue, Google AI

What are some of the issues with the Google AI working on the data from Kepler?

What interesting planets/extraterrestrial objects have you found through Kepler with or without the help of the Google AI sifting though the data?

Spider-Man-2099

One funny issue was downloading the data from the Mikulski Archive for Space Telescopes. At Google, we simply downloaded the data from the public website. But the Kepler dataset is so large that it took about 2 weeks to download, and it didn't even fit on my desktop computer! - Chris Shallue, Google AI

In what direction is the kepler pointing that you gather all your data from? How much of the sky do you miss out on because of the limited coverage? When do you believe something amazing will be discovered?

toomanynames1998

Kepler has looked in a variety of directions. At any one time we see ~ 1/400th of the sky. The Kepler-90i and Kepler-80g planets were found in the original Kepler field which we observed for 4 years. This field is in the constellation Cygnus.

We have been looking at additional parts of the sky, though only for ~ 80 days at a time. So far we have covered an additional 16 fields.

I believe we are discovering amazing things all the time! -Jessie Dotson, NASA Ames Research Center

I'm so excited for this press conference today... I won't know what other questions to ask until after, but I do want to know if google AI will be used to assist the James Webb when it takes over for Hubble. Additionally with the James Webb being so much more powerful, what do you expect to see from this search in the next 10-20 years. Do you think we will be able to confirm for sure that there are habitable (to us) planets with the combined efforts of AI and new James Webb capabilities?

Briebeecher

Google AI or other machine learning tools may well be used for analyzing data from future missions like WEbb, TESS and others. As for these Kepler data where Chris and Andrew worked together on public data, others may mine old or new NASA data to make additional discoveries. In the next decade or two, we anticipate being able to continue to understand the demographics of exoplanets, characterize them (i.e. measure properties such as mass, size etc.) and even directly image them using technologies like coronagraphy or starshades. Our goal is to answer the age old question, "Are we alone?" and with Webb, TESS and future missions we hope to answer that question but it is difficult to say whether that will be in the next decade, or two or more.

-Kartik Sheth, NASA HQ

1.How sure are you that new machine learning method is accurate in defining those objects as 'Planets' but not some other celestial body which are deeply irregular in shape?

1. how do you account for sharp deviations in Raw data when you compare it with prediction by neural network?

vinodkumar95

We confirmed that our machine learning method was accurately classifying signals by testing it on a set of "known" planets and false positives, including false positives caused by two stars orbiting one another. The neural network was able to classify the planets and false positives in our test set accurately 96% in the time. Then, once we identified the new planet candidates (Kepler-90 i and Kepler-80 g) we carefully checked by hand to make absolute sure that the planets were real. Andrew V (UT Austin)

1.How sure are you that new machine learning method is accurate in defining those objects as 'Planets' but not some other celestial body which are deeply irregular in shape?

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vinodkumar95

We tested our machine learning approach by asking it to classify known signals (both planets and false positives like stars passing in front of one another), and found that it was 96% accurate in classifying the false positives and planet candidates.

Then once we had identified new planet candidates, we very carefully checked by hand that they were not false positives by searching for evidence that they might be caused by either data glitches or a star crossing in front of another in the background.

Finally, we calculated the probability that the two new planets were some other kind of false positive and found that the probability was tiny - 1 in 10,000. So we were confident then that the two new planets were real. Andrew V, UT Austin

I heard you confirm 2,225 (I believe) CONFIRMED Keppler found exoplanets...how many total overall have been confirmed to date?

Somesay50

Total exoplanets to date are 3,567, of which 2,525 are from Kepler data. More info here: https://cms.nasa.gov/ames/kepler/briefing-materials-eighth-planet-circling-distant-star-discovered-using-artificial-intelligence (Jessie D.)

Did you use some data generator for training your model?

What was the desing of the neural network?

Were you using TensorFlow with Keras?

Did you use only Kepler data, or some other datasources too, like HatNet?

Lagomorphix

Check out this previous answer for more information about how we designed and trained our model. - Chris Shallue, Google AI

If a planet passes in front of a star it causes a variance in the light. This variance at regular intervals would signal a passing planet. How do you predict the next variance having only witnessed one? How would you know when to look for the next? Is it necessary to view the star for long periods? Is this why we're finding planets with short years? If we are looking for planets with similar lengths of year at similar distance to a star similar to our sun, an exact twin, how is this achieved?

chuckie333

While single transit-like signals are interesting, repeated signals are an important piece of evidence that the signal really is due to a planet. In general, we like to see at least 3 signals before we start to run additional tests to assess whether or not the signal is caused by a planet. This means that we need to be looking at a star for three times longer than the planet's period before we identify it for further analysis. So you're exactly right -- that's part of why we are good at finding short period planets with our transit-detection method. To find longer period planets, we have to be patient! -Jessie Dotson, NASA Ames Research Center

So, we know now that with state-of-the-art data (ie Kepler data) ML techniques can identify exoplanets which were missed by older techniques. Is it likely that the same could be done with lower-quality data? For example, could ML discover new exoplanets using only existing data from ground-based telescopes? Could ground-based data alone for the systems studied by Kepler be sufficient to identify most of the Kepler exoplanets using ML?

5DSpence

Yes, we definitely could use this kind of technique on ground-based data, but for most of the planets discovered by Kepler, you really have to be in space. There's only so much that good data analysis can do.

So, we know now that with state-of-the-art data (ie Kepler data) ML techniques can identify exoplanets which were missed by older techniques. Is it likely that the same could be done with lower-quality data? For example, could ML discover new exoplanets using only existing data from ground-based telescopes? Could ground-based data alone for the systems studied by Kepler be sufficient to identify most of the Kepler exoplanets using ML?

5DSpence

I think that these are exciting avenues for future research, and I wouldn't be surprised if machine learning could help search data from ground telescopes as well. But we won't know for sure until we try! The key ingredient is having a large enough training set of accurately labeled data to train a model. -Chris Shallue, Google AI

Do these planets have moons like our moon? Because if we didn't have a moon, life would not be as we know it now.

Tank_Digravio

We don't know if these planets have moons or not. In theory, transiting moons *might* cause a change in the brightness of the star -- but that signal would be very small. Scientists have been looking for moons around exoplanets (aka exomoons) for quite some time. There are *hints* of exomoons in the Kepler data, but nothing definitive yet. -Jessie Dotson, NASA Ames Research Center

Can we help in the discovery of new exoplanets with citizen science?

Thanks!

quazo33

Yes! All of the data collected by the Kepler spacecraft is available to the public at the NASA Exoplanet Archive (https://exoplanetarchive.ipac.caltech.edu/) and the Mikulski Archive for Space Telescope (https://archive.stsci.edu/index.html). For those just beginning to search for exoplanets, websites like www.planethunters.org and www.exoplanetexplorers.org provide a friendly view of the Kepler data. Good luck and have fun!

-Jessie Dotson, NASA Ames Research Center

What is the resolution of Keplar? If you pointed the scope at say Pluto or Neptune what would you see? What do you see when you find an exoplanet?

MrSunshoes

Kepler's resolution is about 6 arcseconds, which is pretty bad for a space telescope - compare that to Hubble's resolution which is about 60 times better. The reason is that Kepler was designed primarily to look at a large part of the sky at once, at the expense of the high resolution that you could otherwise get from space.

Here's what Kepler saw when it looked at Neptune:

https://www.youtube.com/watch?v=Tw-q3uM_5_0

The images aren't pretty, but the brightness measurements are exquisite! Andrew V, UT Austin

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Does Google charge NASA money for the use of its Machine Learning? If so how much?

fawnykate

We used publicly-available Kepler data to train our machine learning models for this project, and pursued it simply because we thought it was an interesting research challenge to tackle! I did get a cool NASA sticker for my laptop, though :) - Chris Shallue, Google AI

Does anyone have a projected figure, a likely proportion of the 150,00 likely candidate stars with exoplanets, that might have bodies within the 'Goldilocks' parameters?

nostradamuszen

So far 30 stars have been confirmed in the Habitable Zone from the Kepler data with another 20 candidates still to be confirmed. But the data are still being analyzed so stay tuned.

Kartik Sheth (NSA HQ)

If the Machine learning model was trained on datasets in which humans classified which signals are planet and which are not. Isn't the model biased?

rajan314

The neural network model needed to train on a vetted-database in order to identify an exoplanet (from a false positive) in the light readings. Once the model "learned" how to do this, it was used on data from 670 systems to pick up weaker signals of exoplanets. That's how these two new planets were found. (Jessie D.)

What would you do if you did discover life on the planet?

Sciencenerd5893

The planet Kepler-90i is not likely to have life since it is so close to the star Kepler 90 that the surface temperature is 800 F. And we don't have any way of discovering life on Kepler-90i since it is so far away and so close to its star. But if we did discover life, we would announce it to the world. Paul Hertz, NASA

Just a bit confused,

You said that you used CNN for selecting the exoplanet-candidate list. To the best of my knowledge, CNN is good with 2D array of data. The input of CNN is just a light curve of the star or images ?

Boltfox

Great question! You're right that convolutional neural networks are often used for 2D images, but they can also be used for N-dimensional arrays of data. In fact, *color* images are actually 3D arrays of data, because they have two spatial dimensions *and* a color dimension (RGB). Color videos are 4D arrays of data, because they also have a time dimension.

In this project, we trained a 1D convolutional neural network. The input to the CNN is the one-dimensional light curve, which is an array of brightness measurements over time. - Chris Shallue, Google AI

Is the makeup of Kepler 90i comparable to our own sun?

SentientStardust96

Like the sun and almost all stars (at least during most of their lifetimes), Kepler-90 is mostly made of hydrogen and helium. It also happens to have a similar amount of heavy elements (like iron) to the Sun - maybe about 25% more. Andrew V (UT Austin)

When you say Kepler-90 is Sun-like, can we know if it is similar in age as well? Only, the planets of K90 are so close together that if they had been around for 4.5 billion years would there not have been resonance issues? Maybe even planets ejected from the system?

Captain_Username

It's notoriously difficult to figure out the ages of stars, but from everything we can tell, Kepler-90 is probably about the same age as the sun or maybe a bit older.

The Kepler-90 planets are much closer packed than the solar system planets, which indeed raises the question about whether they are stable, it turns out that calculations have shown that they are (see https://arxiv.org/abs/1310.5912 Section 4.8).

Hey y'all, I just gave the paper a real quick read so apologies if I get the details wrong.

My understanding is that the inputs to your neural net are "threshold crossing events" (TCEs), which are candidate signals that *might* contain a planet. From that, the neural net returns "planet" or "no planet" and how confident it is.

It also sounds like there is a significant amount of pre-processing to go from raw measurement data to an input TCE that's suitable for the neural net to work with: calibration, aperture selection, threshold detection, flattening, etc are mentioned. Do you think it would be possible to incorporate some type of intelligence / machine learning to improve certain parts of *that* process as well?

SkywayCheerios

That's correct - a lot of pre-processing (flattening and binning) goes into preparing the light curves to be sent into the neural network. I think that decreasing the pre-processing and replacing that with some kind of machine-learning process (or just teaching the machine learning models to just use the raw data as is) is an important step forward. For now, we're doing the simple thing, but I think there's a lot of promise to that approach. Andrew V, UT Austin

I know there are a bunch of different classes of stars. Are there any classes of stars that which are easier or harder to find exoplanets? If so, what makes it easier or harder?

Aovermille

There are a couple of different methods for finding exoplanets. Kepler was designed to use the transit method -- where we see the host star briefly get dimmer as the planet passes between us and its star. The amount of dimming depends on the relative size of the star and the planet. As a result, planets around smaller stars will produce more dimming, which makes it easier to detect planets around smaller stars. And conversely, planets around larger stars produce less dimming -- making planets around those stars harder detect. - Jessie Dotson, NASA Ames Research Center

How close do you think we are to finding a planet that has all the signs of being suitable for life on Earth?

Valladarex

Today's telescopes are good at finding planets but not at finding signs of habitability. We are working on the technology needed for future telescopes that can detect signs if habitability. The James Webb Space Telescope, launching in 2019, will be the first step toward that goal. Paul Hertz, NASA

What did you do in college to get a course like this and Is there an easy barrier to entry to get in. I know things are different in America(am Irish) so refer to school elements in lay mans terms

Also can you get good pictures from earth when you find a planet or any at all

Cavan_for_sam

Most astronomers, like Andrew, Jessie or myself tend to do an undergraduate degree in physics, astronomy or mathematics, and then go on to get a graduate degree in astronomy and astrophysics.

Regarding pictures from the earth, the difficulty is blocking the light from the parent star to detect the very faint planet around it. This is usually done with a technique called coronagraphy in the visible or near-infrared -- and the Gemini telescope has been able to image a planet although the image is not resolved. Another ground-based telescope that may be able to image a planet (or rather the dust in planet building zones around a star) is ALMA - a millimeter/submillimeter interferometer.

-Kartik Sheth, NASA HQ

Are there specific insights gained through this discovery and the machine learning process that led to it, that may influence the design of the next generation of planet-hunting instruments ?

GloriousDawn

Today's result highlights that planetary systems come in a variety of configurations -- and that there's a lot we don't yet know. It also demonstrates the importance of developing and utilizing sophisticated algorithms in addition to designing and building more powerful telescopes. -Jessie Dotson, NASA Ames Research Center

When and how is Kepler data made available for citizen scientists who want to pursue their own analysis, using AI or other approaches? E.g. if you hadn't made this discovery, when would an outside analyst have been able to make it?

nealmcb

All data resulting from the Kepler space telescope is publicly available. It can be downloaded from the Mikulski Archive for Space Telescope! or the NASA Exoplanet Archive!. Anyone who wants to download the data to pursue their own analysis, using any approach is encouraged to do so! -Jessie Dotson, NASA Ames Research Center

I'm sure I can't see it directly, but if I wanted to look in its general direction how would I find Kepler-90i in the nighttime sky?

toyoagz

Kepler-90 is in the constellation Draco. -Jessie Dotson, NASA Ames Research Center

Obviously we are not alone so my question is when will NASA admit other life forms are plentiful out there?

Tangled_Wires

The only life we know about is on Earth. NASA is always looking for life out there, and when we find it, we will tell you. Paul Hertz, NASA

How many other solar systems are currently being observed and do any of them have a planet that could potentially sustain life?

skiboy625

During its prime mission, Kepler observed over 150,000 stars and those data are still being analyzed. K2 (the extension of the Kepler mission) has observed an additional 200,000+stars. Searches for planets around other stars are also underway from ground based telescopes such as SPECULOOS, MEarth, and others. Many of these stars have planets that are in the habitable zones (defined as the distance from a star where liquid water can exist) but we do not know yet which of these might sustain life. For example, in our Solar System, Mars, Earth and Venus all are in the "habitable zone" and yet life only exists on Earth.

-Kartik Sheth (NASA HQ)