

Convolutional Neural Networks for Exoplanet Detection in Photometric Light Curves From Massive Data Surveys

Stela Ishitani Silva, Greg Olmschenk, Richard K. Barry and MOA Collaboration

NASA Goddard Space Flight Center

Machine Learning in Astronomical Surveys #2

IAP/CCA - Nov 28, 2023

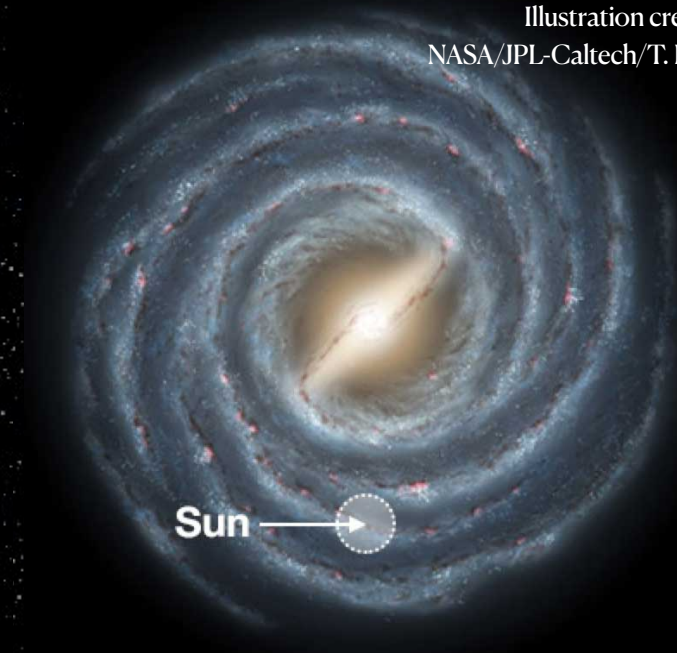


Milky Way
Illustration credit:
NASA/JPL-Caltech/T. Pyle

Sun →

Milky Way
contains hundreds of
billions of stars

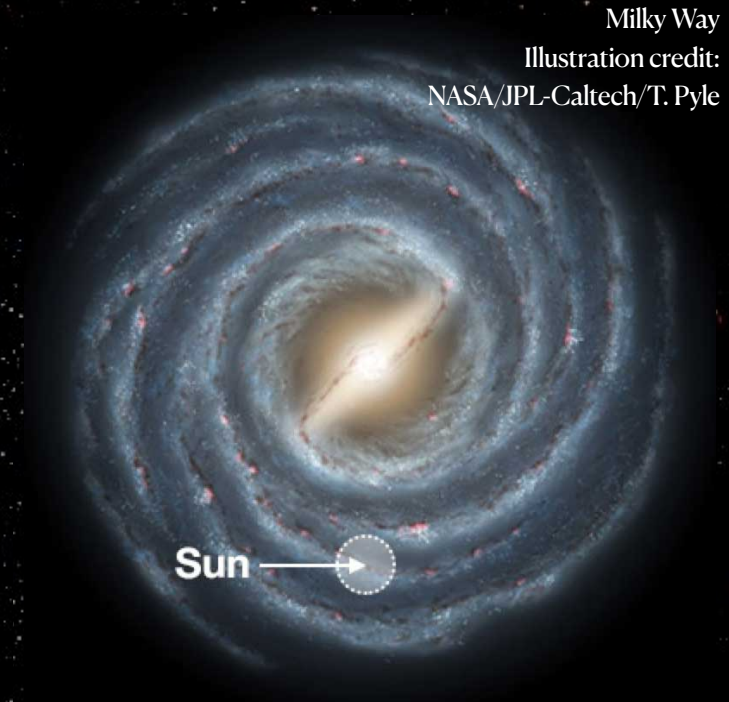
Milky Way
Illustration credit:
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Milky Way
contains hundreds of
billions of stars



Exoplanets are more
common than stars



Milky Way

Illustration credit:
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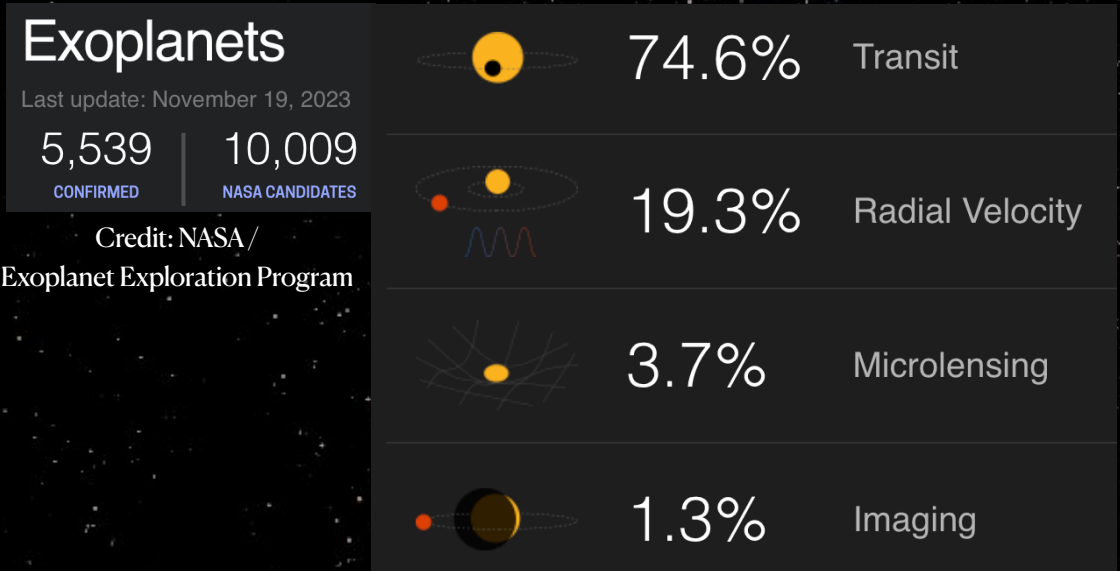
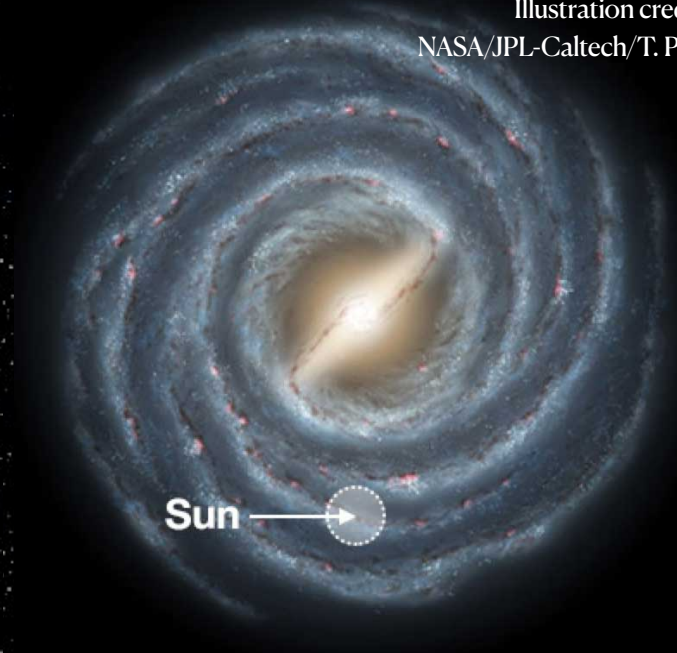
Sun

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How to detect them?

Exoplanets are more
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Milky Way
Illustration credit:
NASA/JPL-Caltech/T. Pyle

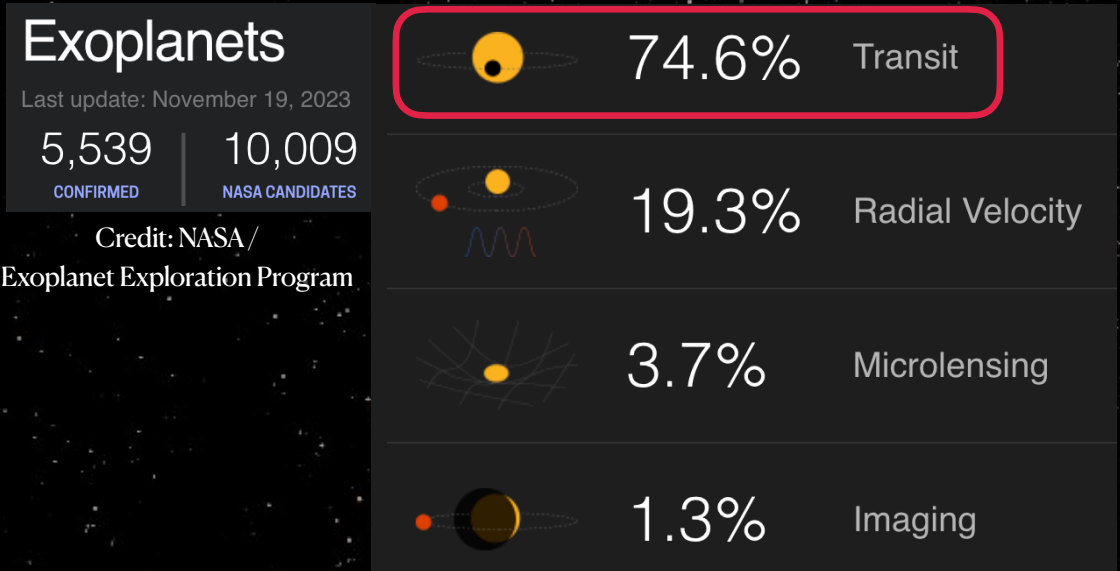
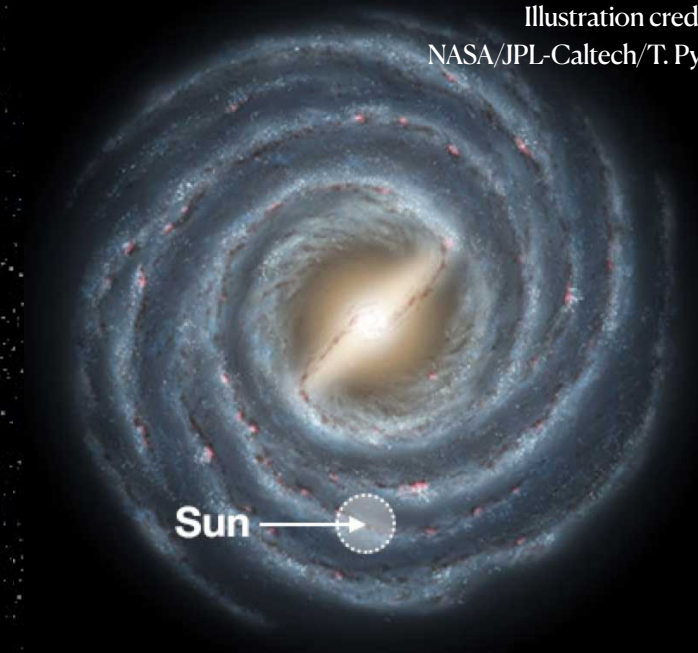


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How to detect them?

Exoplanets are more common than stars

Milky Way
Illustration credit:
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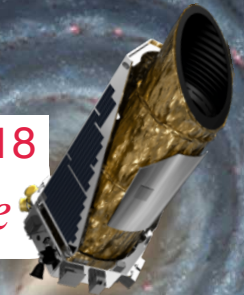
Milky Way contains hundreds of billions of stars

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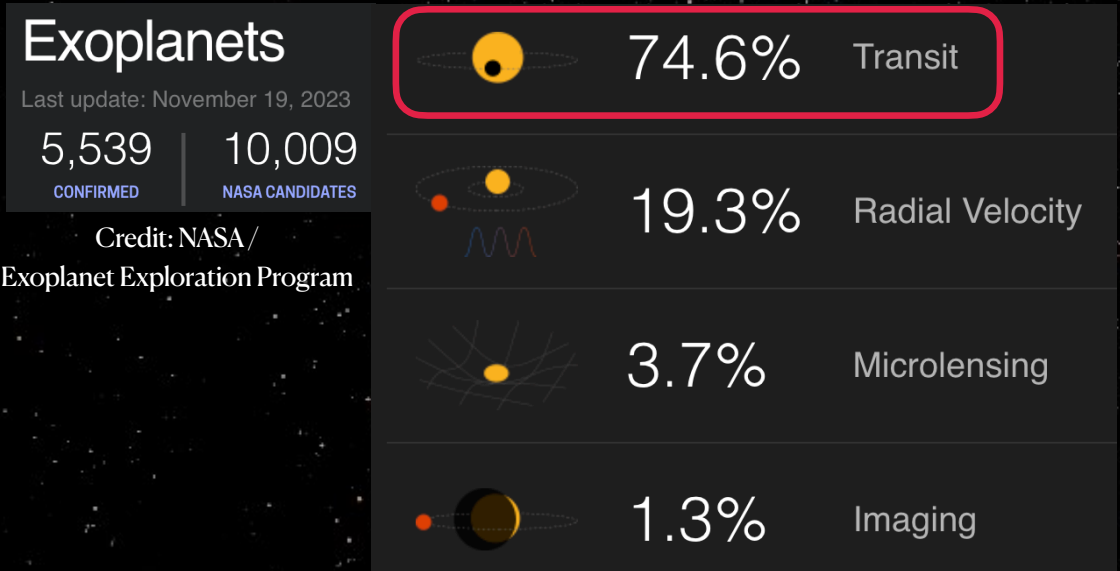
Exoplanets are more common than stars

retired on 2018

Kepler Space Telescope



Sun



Exoplanets
 Last update: November 19, 2023
 5,539 CONFIRMED | 10,009 NASA CANDIDATES
 Credit: NASA/ Exoplanet Exploration Program

Milky Way contains hundreds of billions of stars

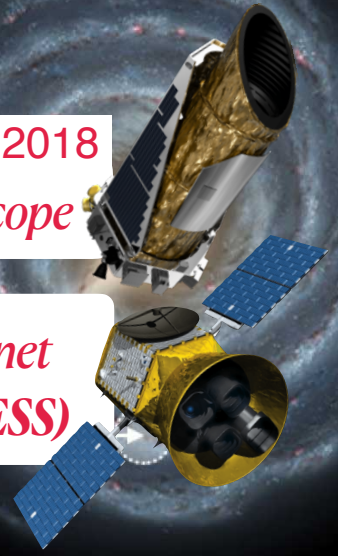
How to detect them?

Exoplanets are more common than stars

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Kepler Space Telescope

Transiting Exoplanet Survey Satellite (TESS)



Exoplanets

Last update: November 19, 2023

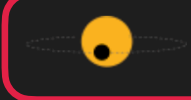
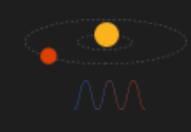


5,539

CONFIRMED

10,009

NASA CANDIDATES

Credit: NASA/
Exoplanet Exploration Program

	74.6%	Transit
	19.3%	Radial Velocity
	3.7%	Microlensing
	1.3%	Imaging

Milky Way contains hundreds of billions of stars

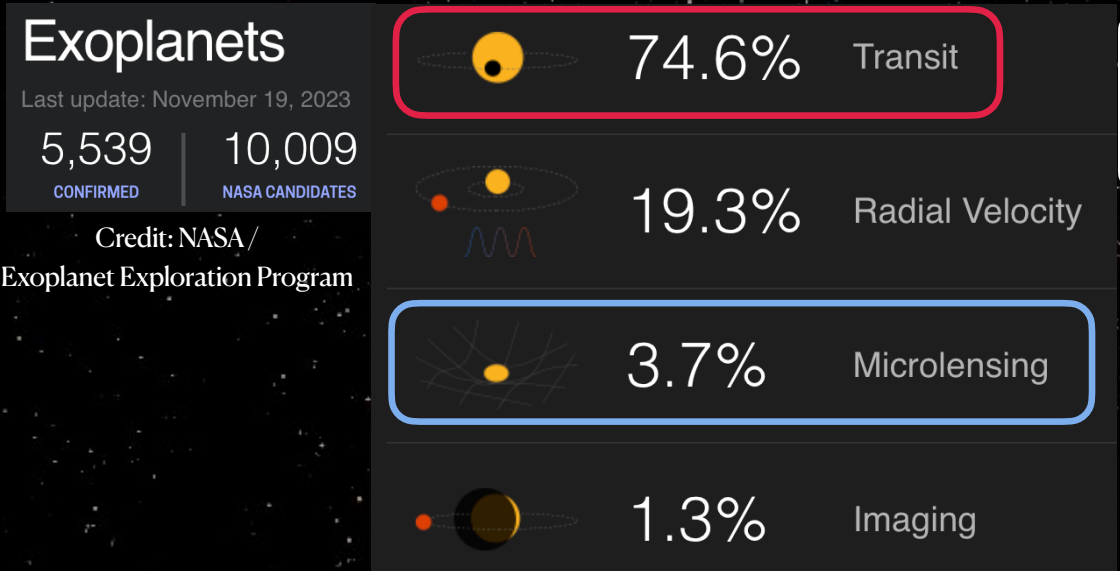
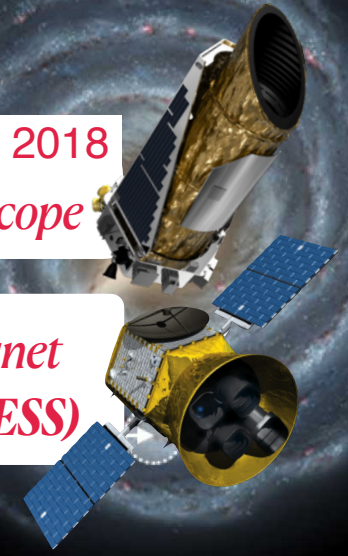
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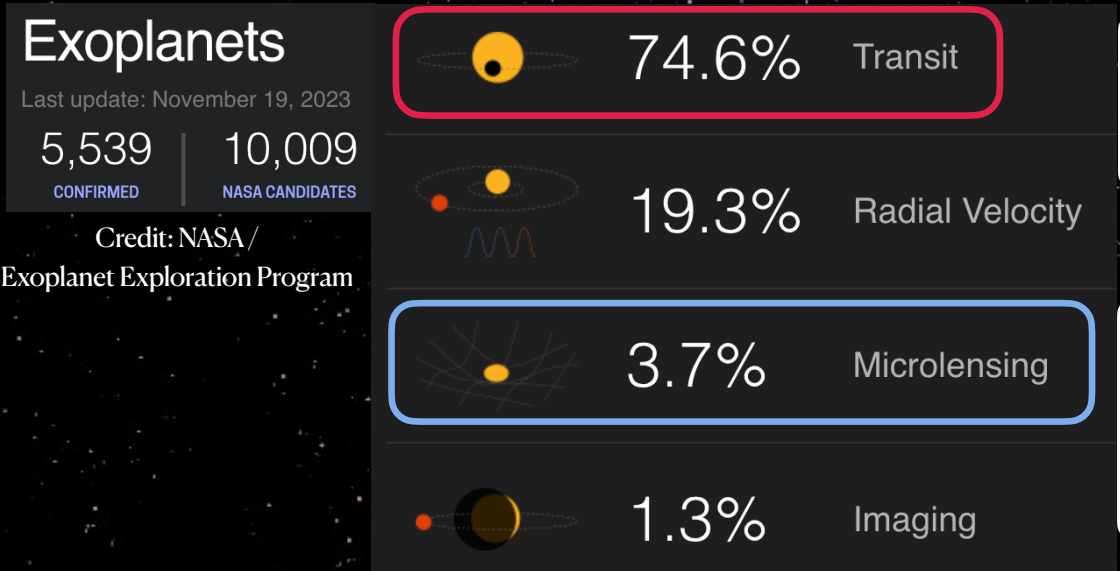
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Milky Way contains hundreds of billions of stars

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Exoplanets are more common than stars



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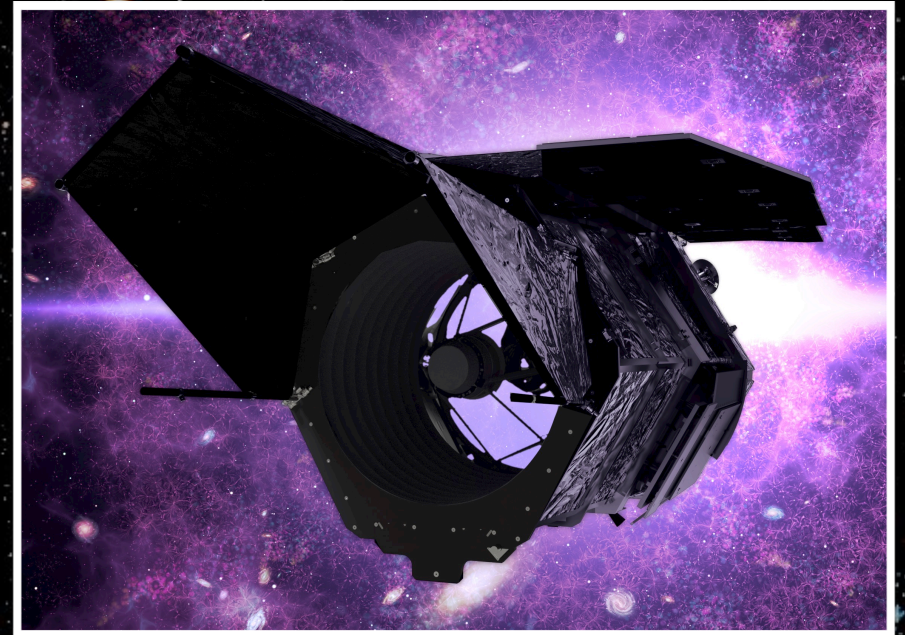
retired on 2018
Kepler Space Telescope

Transiting Exoplanet Survey Satellite (TESS)

Nancy Grace Roman Space Telescope
to be launched no later than 2027



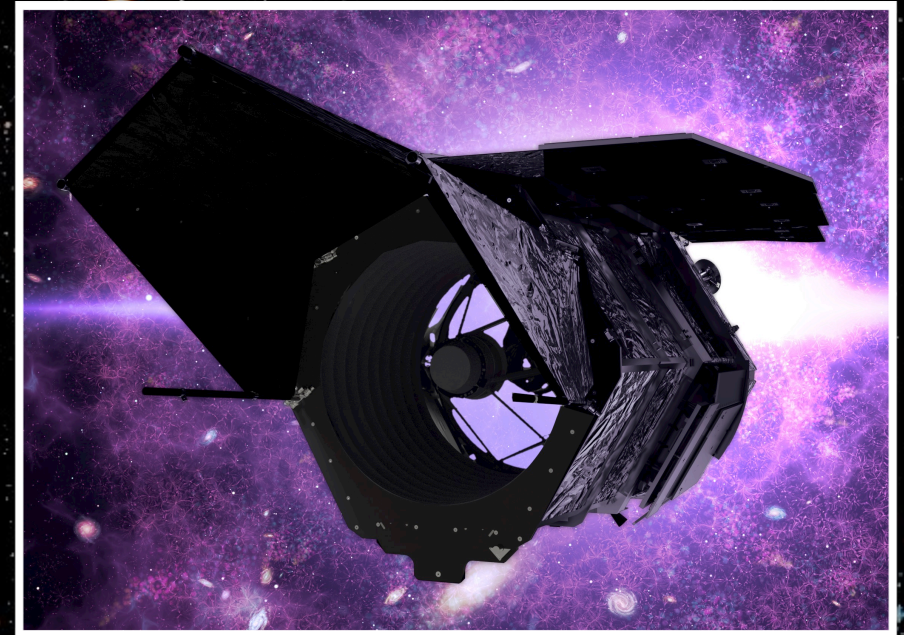
The Nancy Grace Roman Space Telescope





The Nancy Grace Roman Space Telescope

Top-priority large space mission of the 2010
Astronomy and Astrophysics Decadal Survey





The Nancy Grace Roman Space Telescope

Top-priority large space mission of the 2010
Astronomy and Astrophysics Decadal Survey

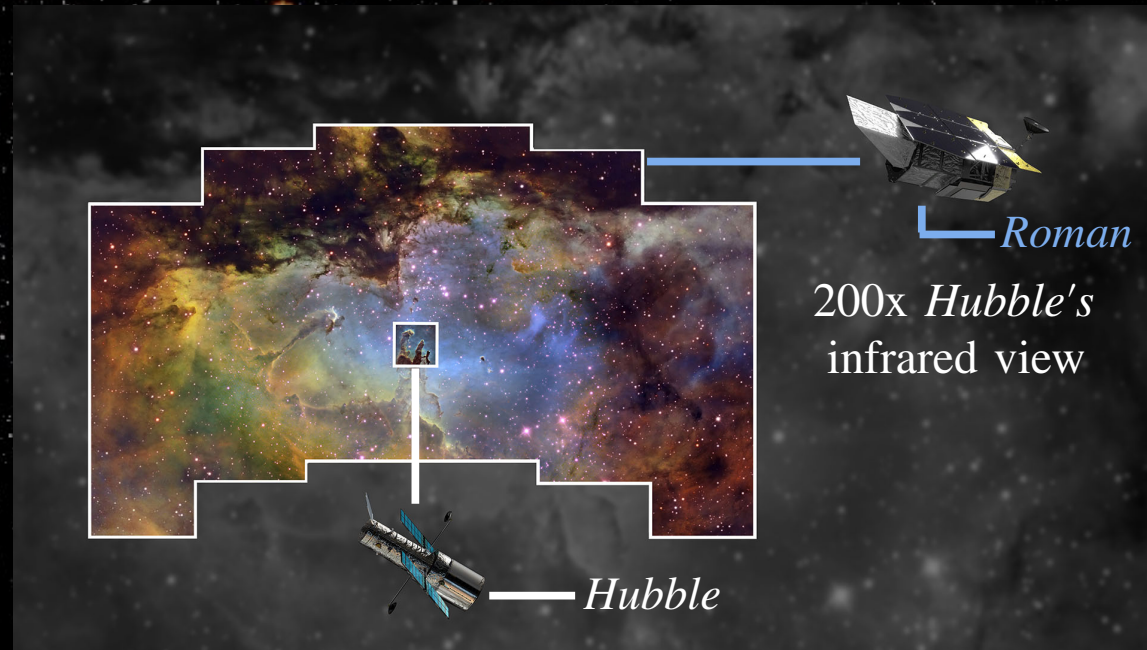


Image Credit: NASA GSFC/JPL-STScI-Caltech



The Nancy Grace Roman Space Telescope

Top-priority large space mission of the 2010
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Hundred of millions of precise light curves!



Image Credit: NASA GSFC/JPL-STScI-Caltech



The Nancy Grace Roman Space Telescope

Top-priority large space mission of the 2010 Astronomy and Astrophysics Decadal Survey

Hundred of millions of precise light curves!

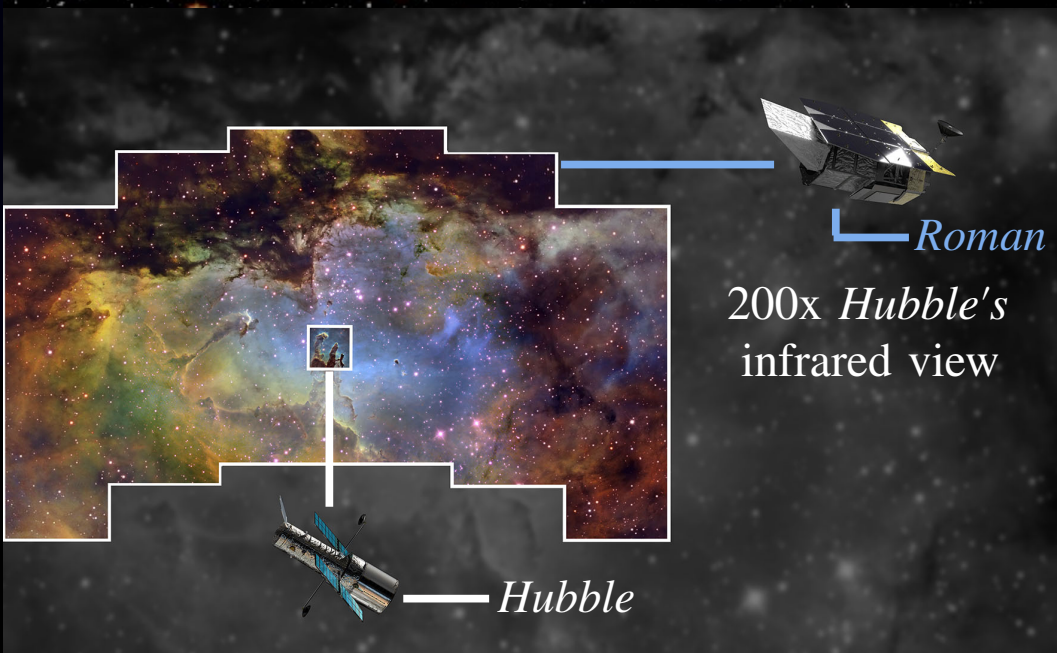
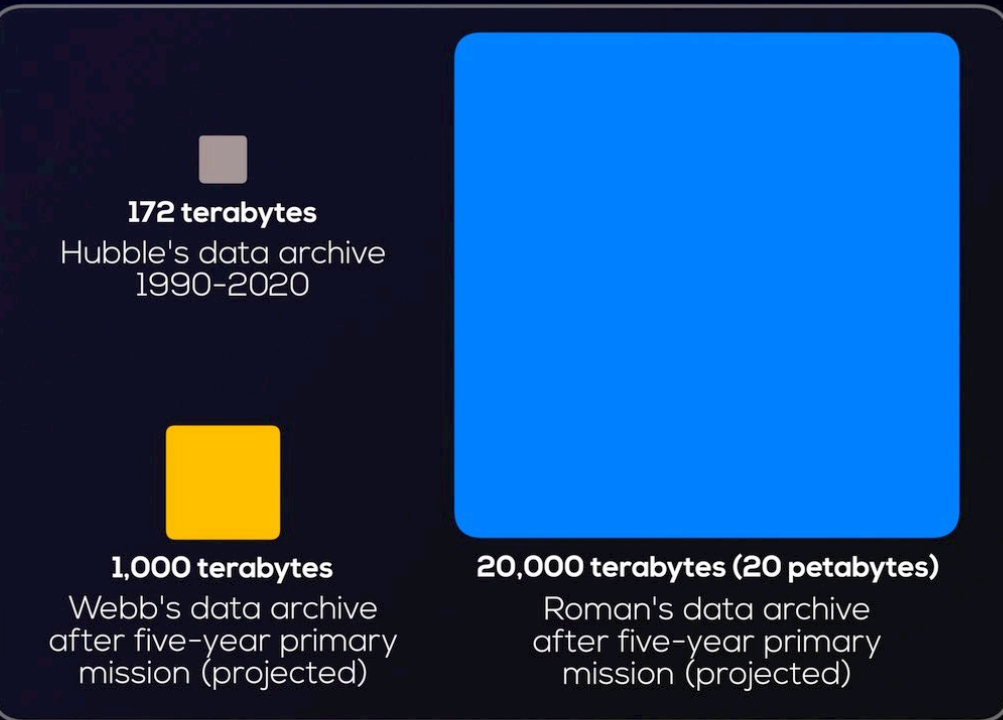


Image Credit: NASA GSFC/JPL-STScI-Caltech

Image credit: NASA GSFC



The Nancy Grace Roman Space Telescope

Top-priority large space mission of the 2010 Astronomy and Astrophysics Decadal Survey

Hundred of millions of precise light curves!

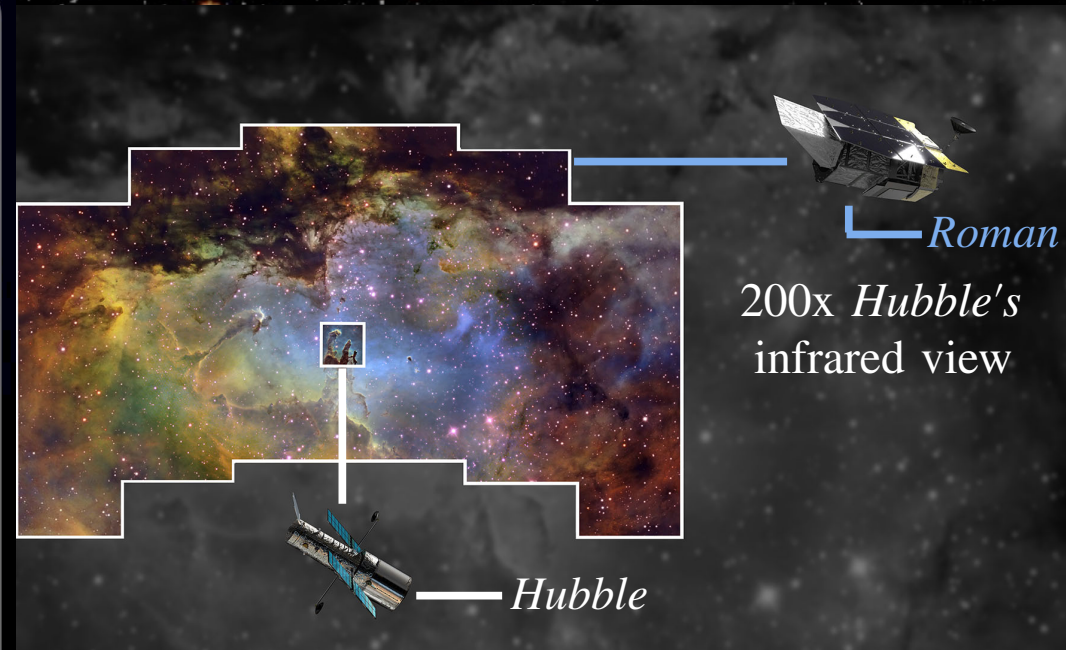
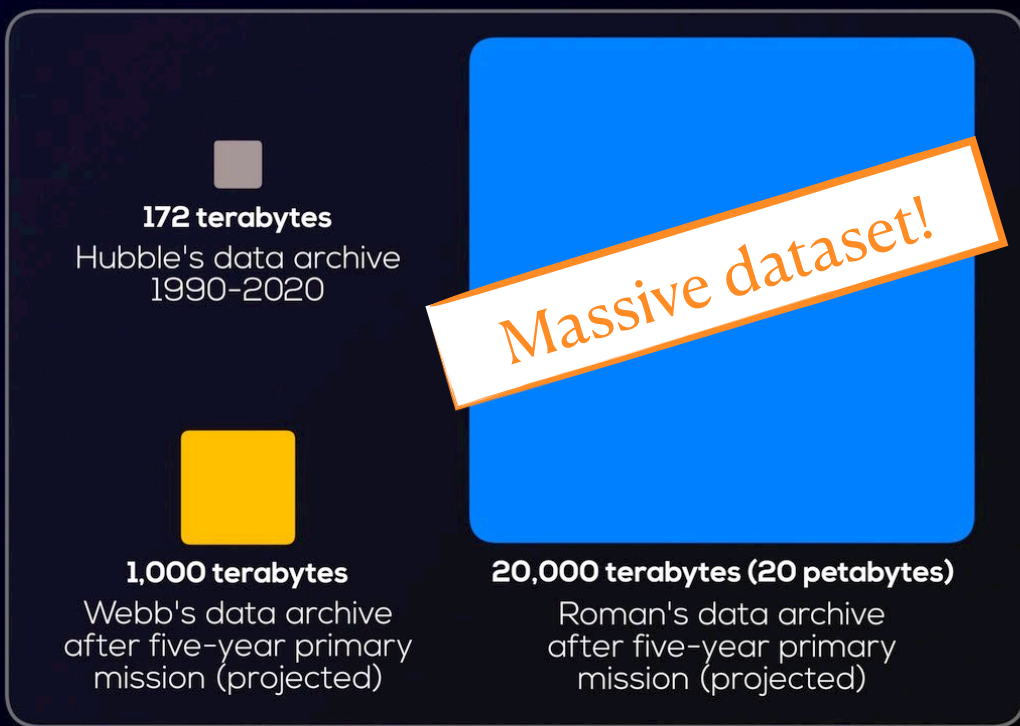


Image Credit: NASA GSFC/JPL-STScI-Caltech

Image credit: NASA GSFC



The Nancy Grace Roman Space Telescope

Top-priority large space mission of the 2010 Astronomy and Astrophysics Decadal Survey

Hundred of millions of precise light curves!
How to mine for microlensing exoplanets?

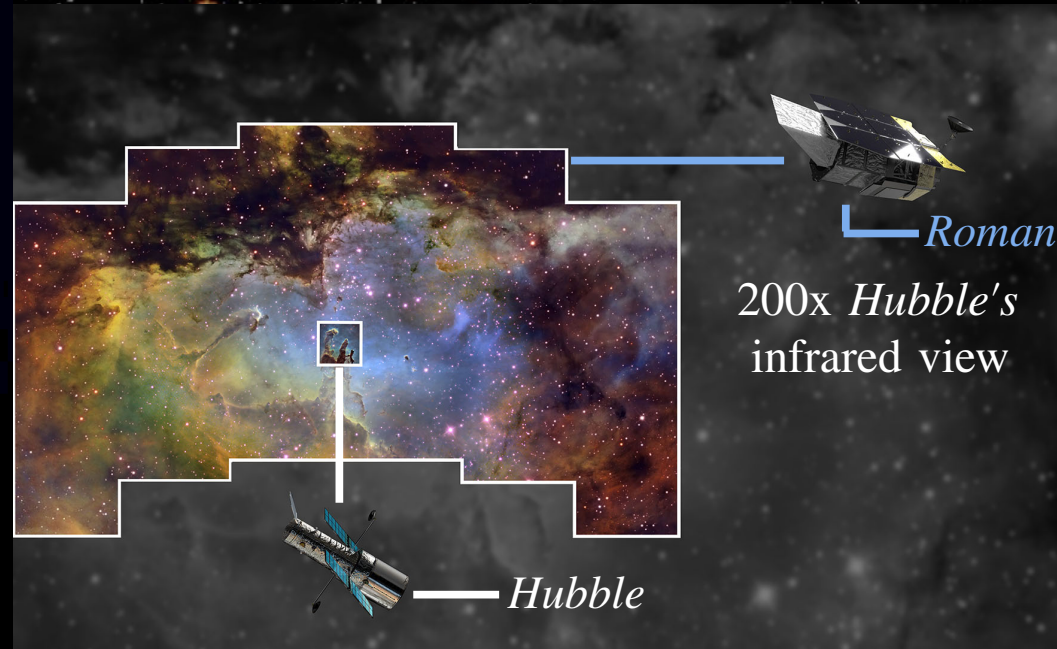
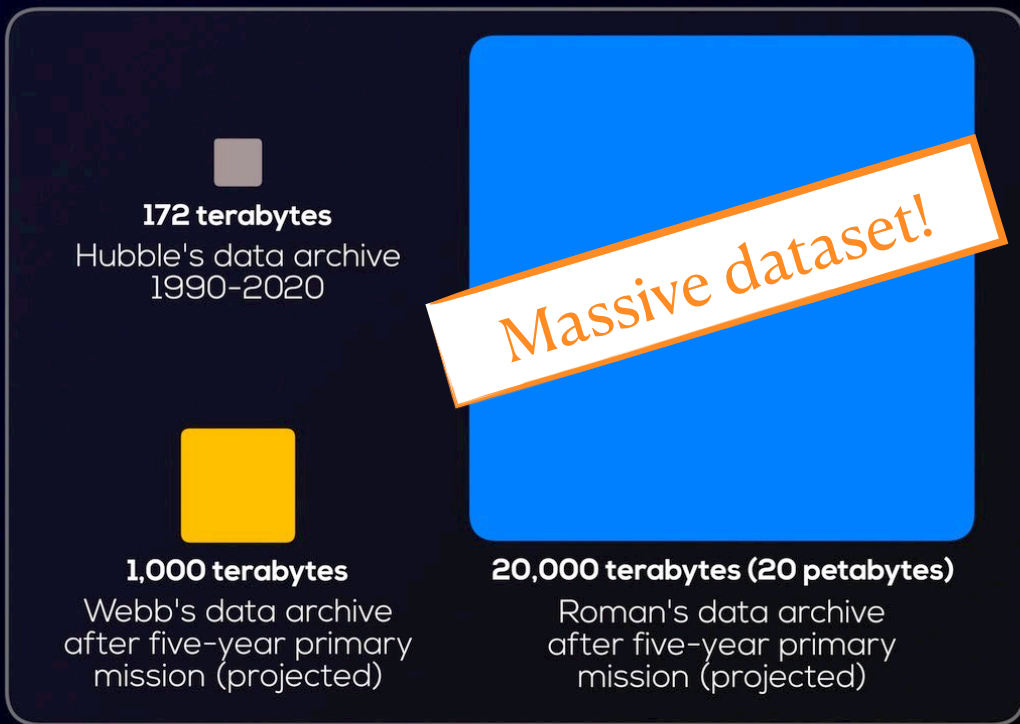


Image Credit: NASA GSFC/JPL-STScI-Caltech

Image credit: NASA GSFC

Neural Networks for Mining Photometric Light Curves in Massive Datasets





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CNN for Planetary Transits

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CNN for Planetary Transits



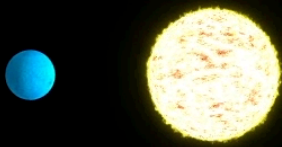
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CNN for Planetary Transits

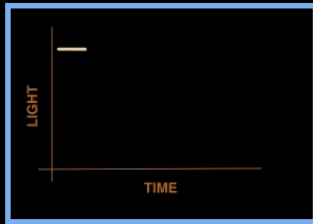


Planetary Transit 101



TESS light curves
to search
for new candidates

Convolutional
Neural
Network



Light curve

Animation credit: NASA/Exoplanet Exploration Program

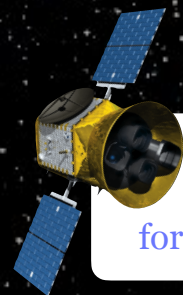
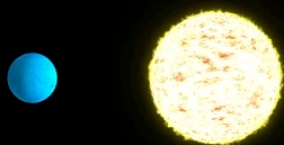
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CNN for Planetary Transits

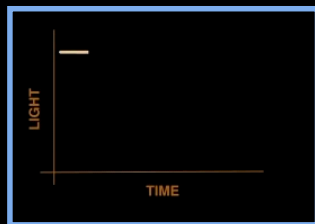


Planetary Transit 101



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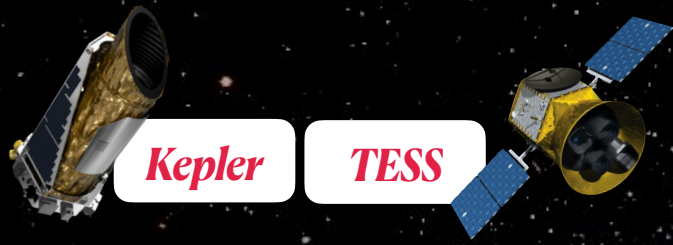
Light curve

Animation credit: NASA/Exoplanet Exploration Program

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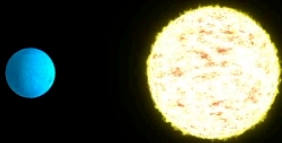
CNN for Planetary Transits



Kepler

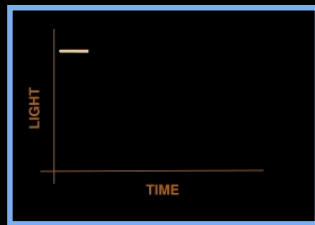
TESS

Planetary Transit 101

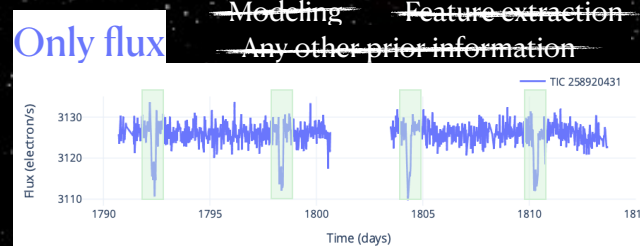


TESS light curves
to search
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Convolutional
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Light curve



Animation credit: NASA/Exoplanet Exploration Program

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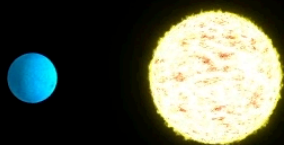
CNN for Planetary Transits



Kepler

TESS

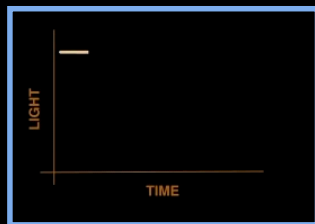
Planetary Transit 101



Data with examples of confirmed transiting exoplanets

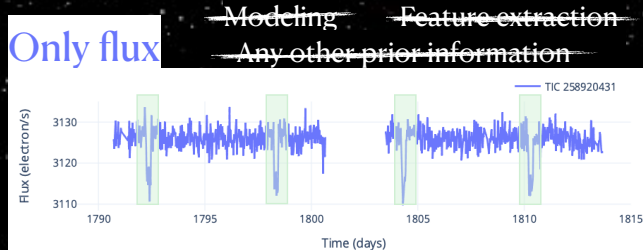
TESS light curves to search for new candidates

Convolutional Neural Network



<1%

Light curve

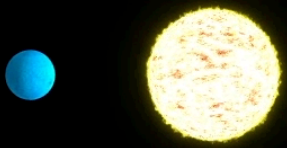
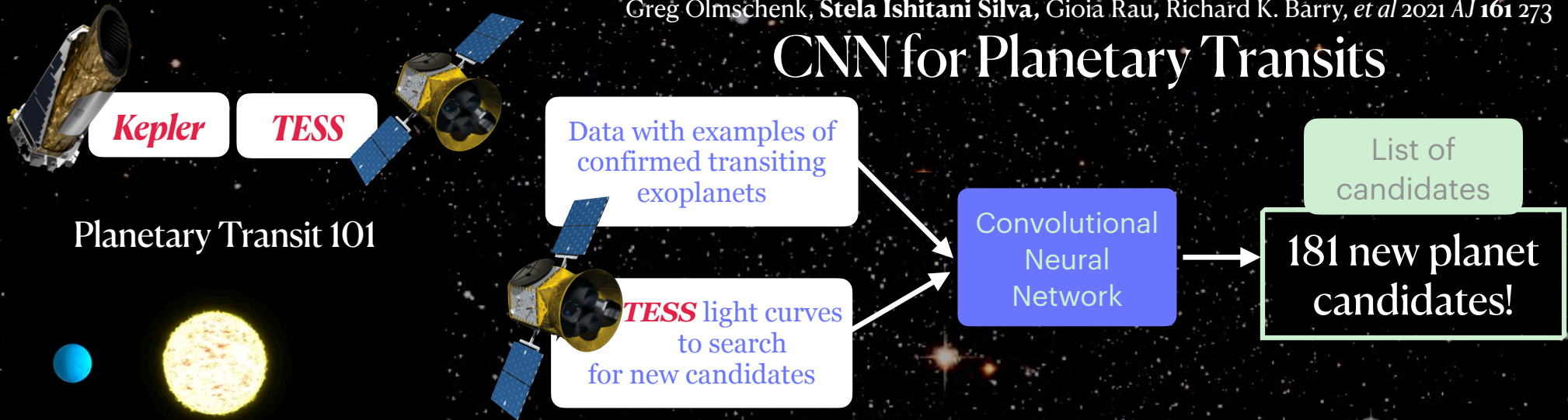


Animation credit: NASA/Exoplanet Exploration Program

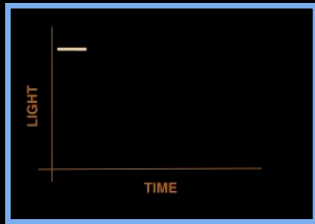
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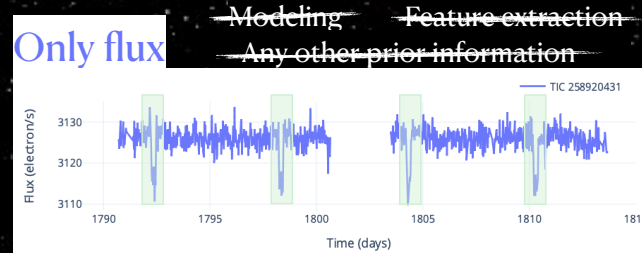
CNN for Planetary Transits



Planetary Transit 101



Light curve

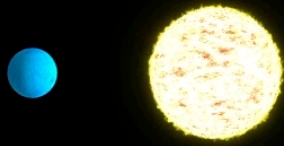
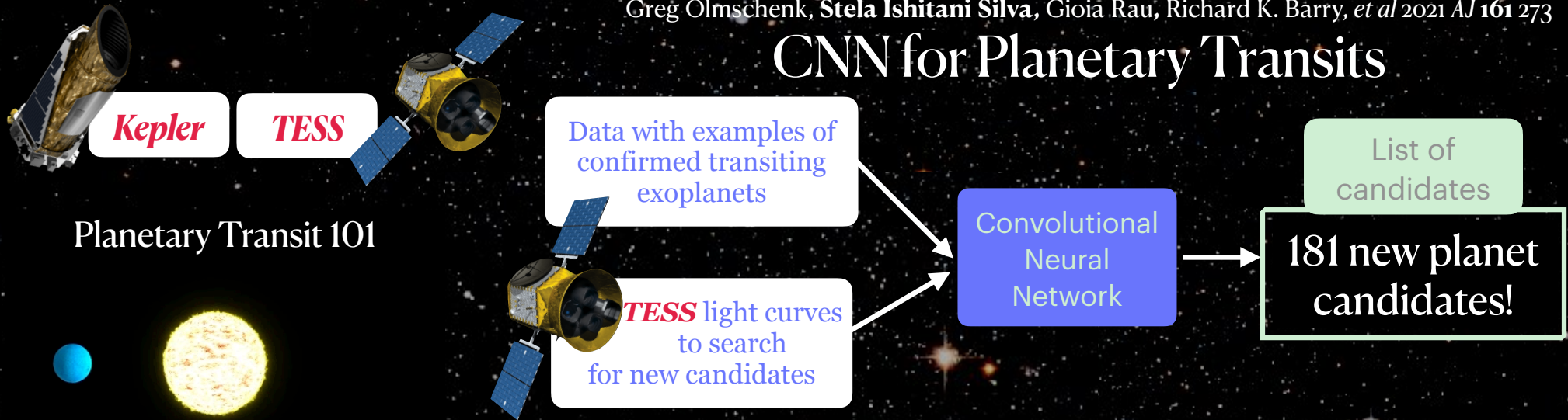


Animation credit: NASA/Exoplanet Exploration Program

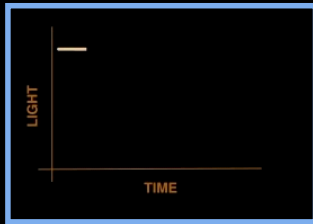
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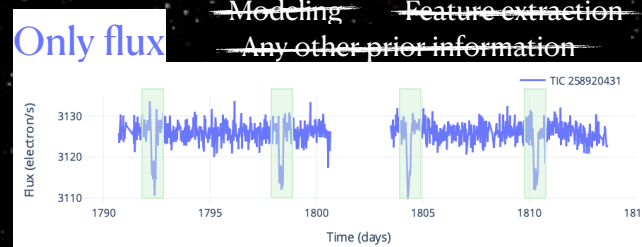
Planetary Transit 101



Light curve

<1%

f



~~Modeling~~ ~~Feature extraction~~
~~Any other prior information~~

CNNs can learn this function f on its own

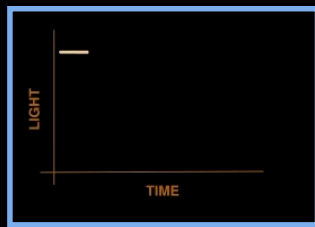
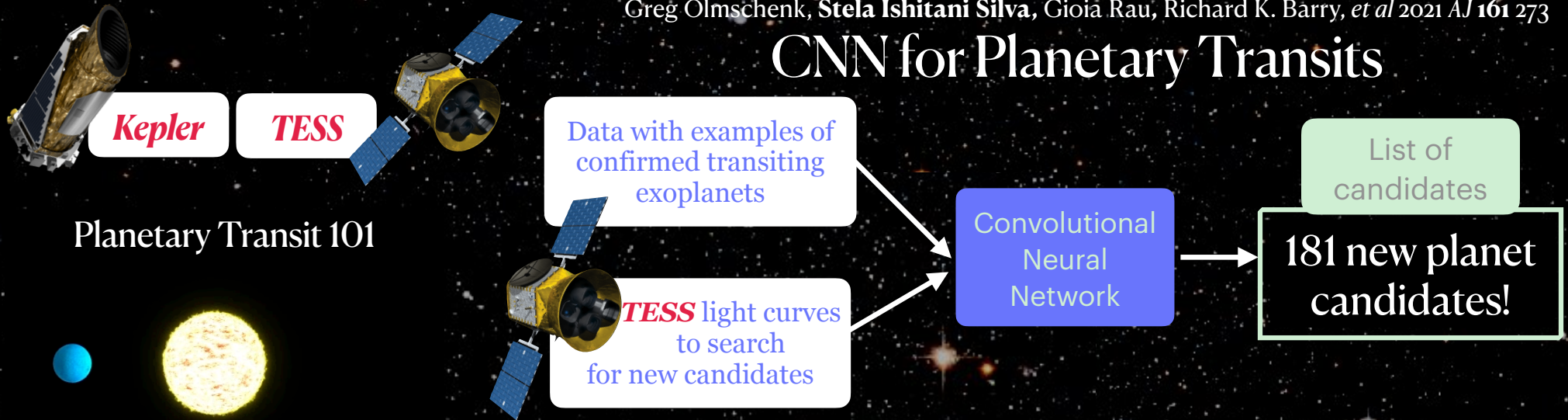
Prediction

Animation credit: NASA/Exoplanet Exploration Program

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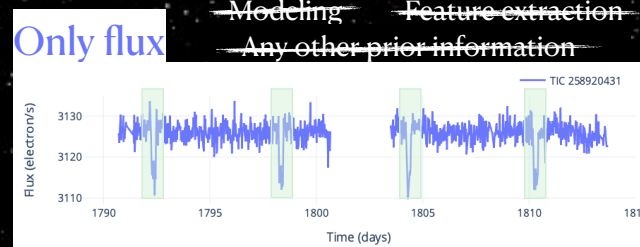
CNN for Planetary Transits



Light curve

$<1\%$

f



Recognize features in light curves

CNNs can learn this function f on its own

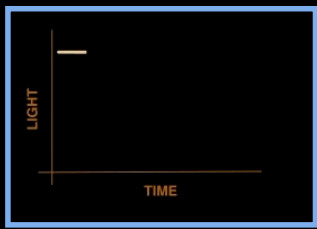
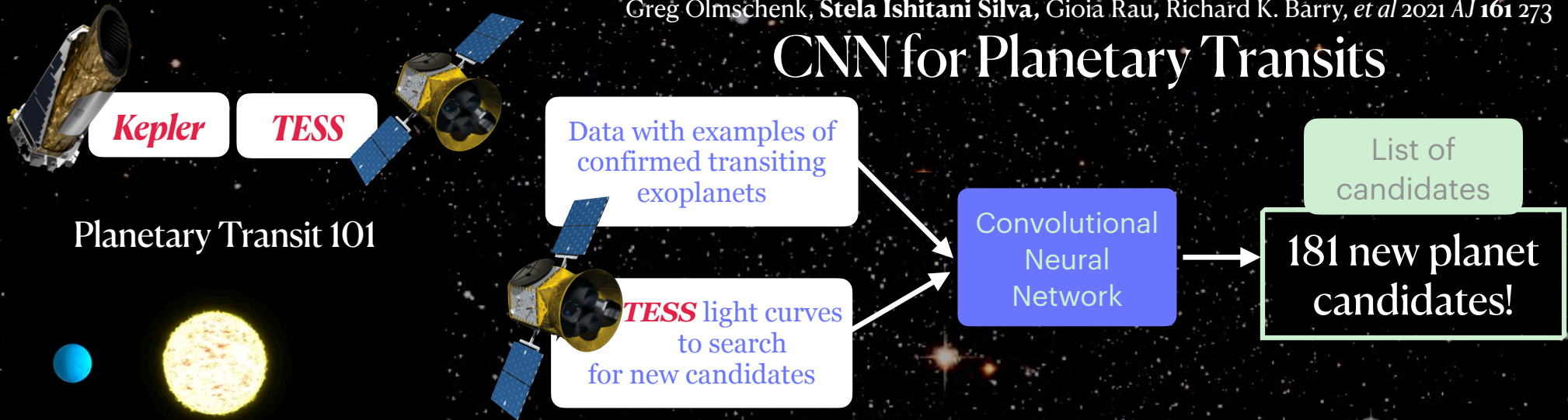
Prediction

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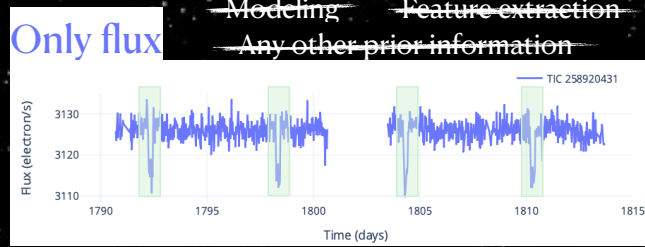
Greg Olmschenk, Stela Ishitani Silva, Gioia Rau, Richard K. Barry, *et al* 2021 *AJ* 161 273

CNN for Planetary Transits



Light curve

f



Recognize features in light curves

CNNs can learn this function f on its own

Prediction

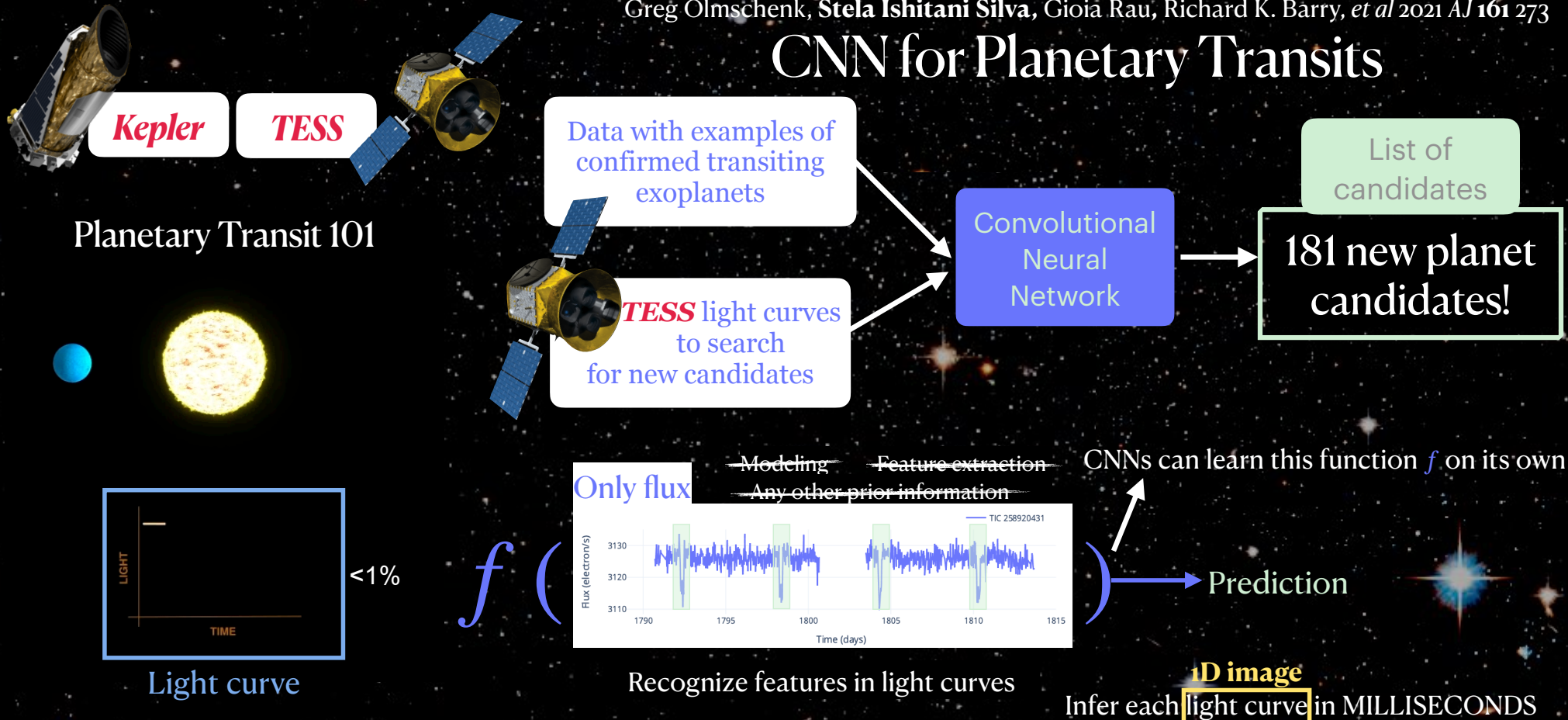
Infer each light curve in MILLISECONDS

Animation credit: NASA/Exoplanet Exploration Program

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CNN for Planetary Transits



Animation credit: NASA/Exoplanet Exploration Program

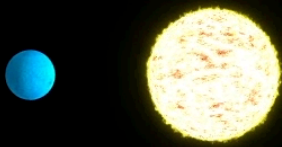
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CNN for Planetary Transits



Planetary Transit 101



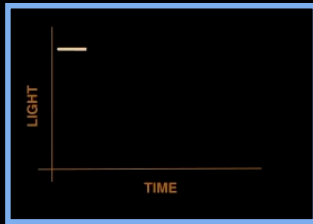
Data with examples of confirmed transiting exoplanets

TESS light curves to search for new candidates

Convolutional Neural Network

List of candidates

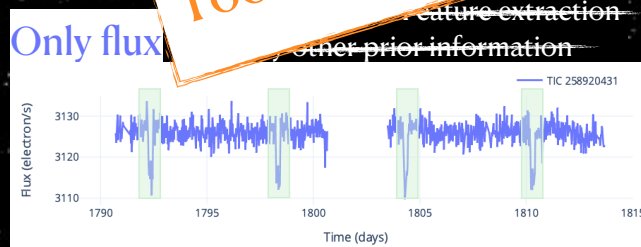
Tool to mine light curves in massive datasets!



Light curve

<1%

f



Only flux feature extraction
No other prior information

Recognize features in light curves

CNNs can learn this function f on its own

Prediction

1D image

Infer each light curve in MILLISECONDS

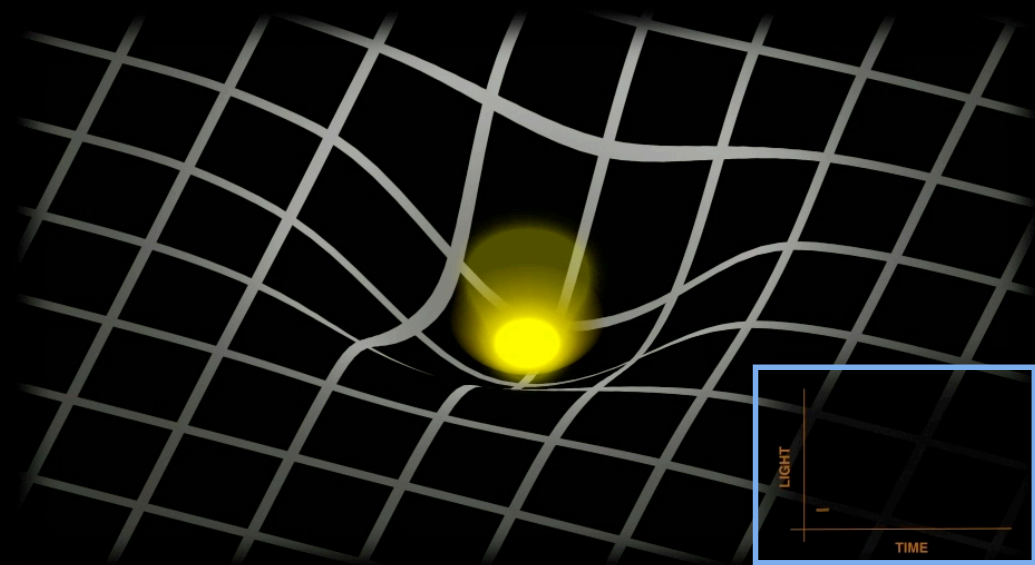
Animation credit: NASA/Exoplanet Exploration Program





Currently: Ground-based wide field telescopes

Gravitational Microlensing 101

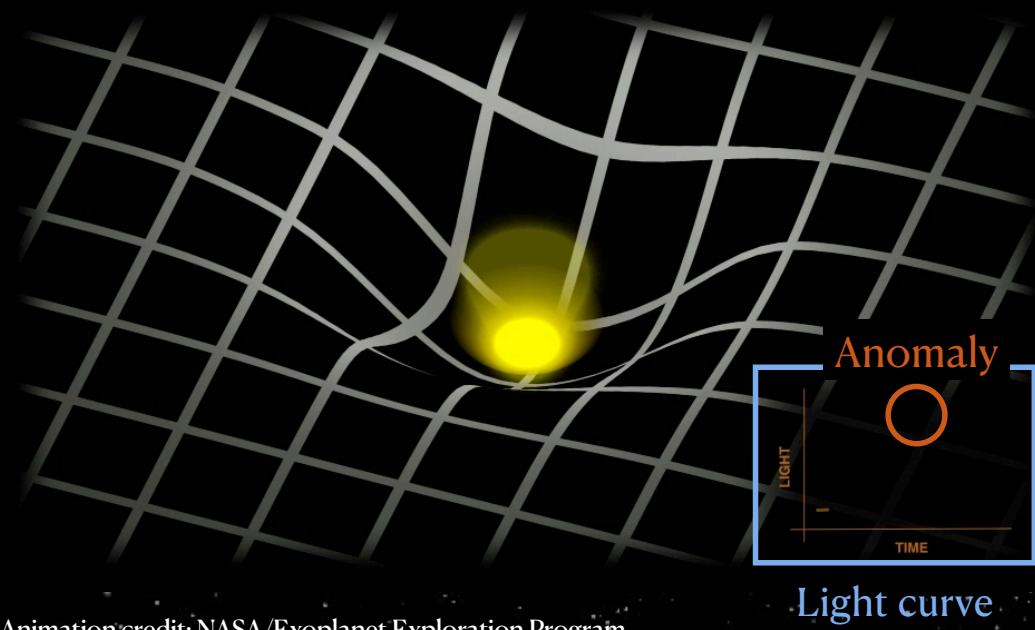


Light curve

Animation credit: NASA/Exoplanet Exploration Program



Gravitational Microlensing 101

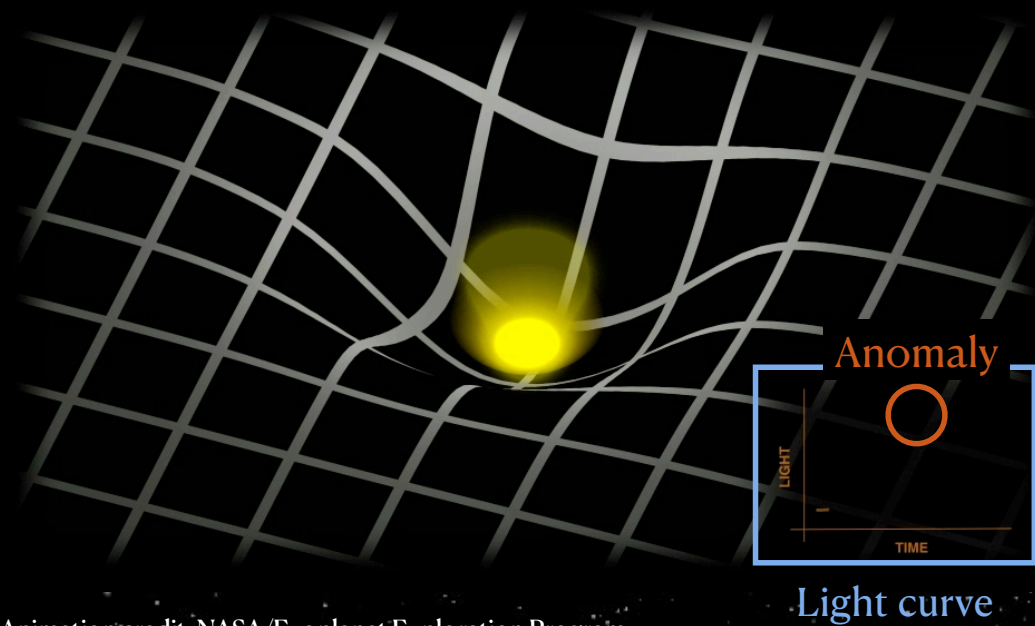


Animation credit: NASA/Exoplanet Exploration Program



- Traditional selection approaches:
 - Good for detecting single lens events

Gravitational Microlensing 101

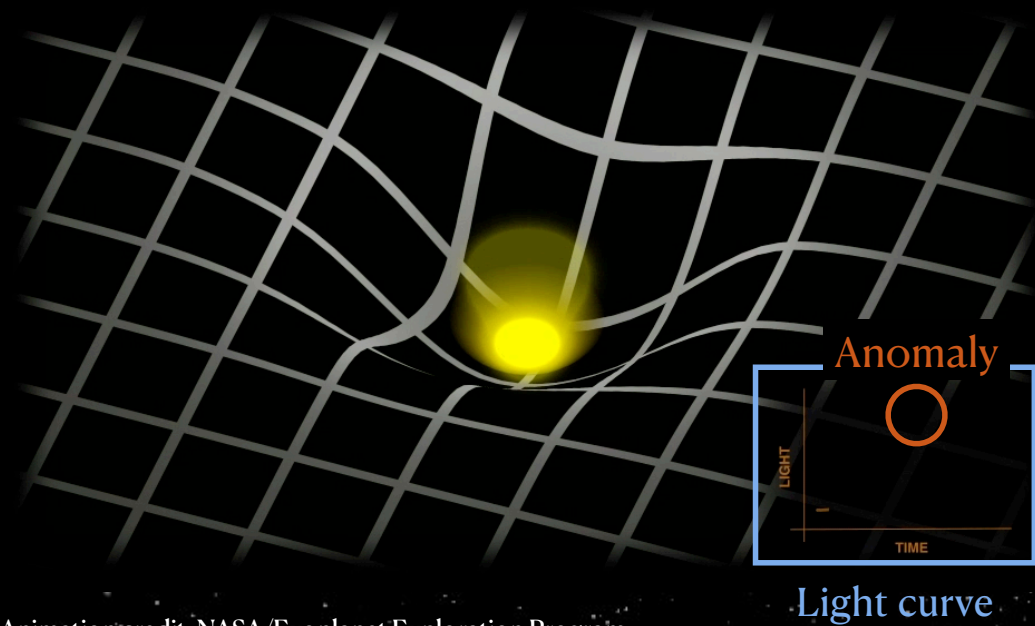


Animation credit: NASA/Exoplanet Exploration Program



- Traditional selection approaches:
 - Good for detecting single lens events
 - Can miss multiple lenses events

Gravitational Microlensing 101

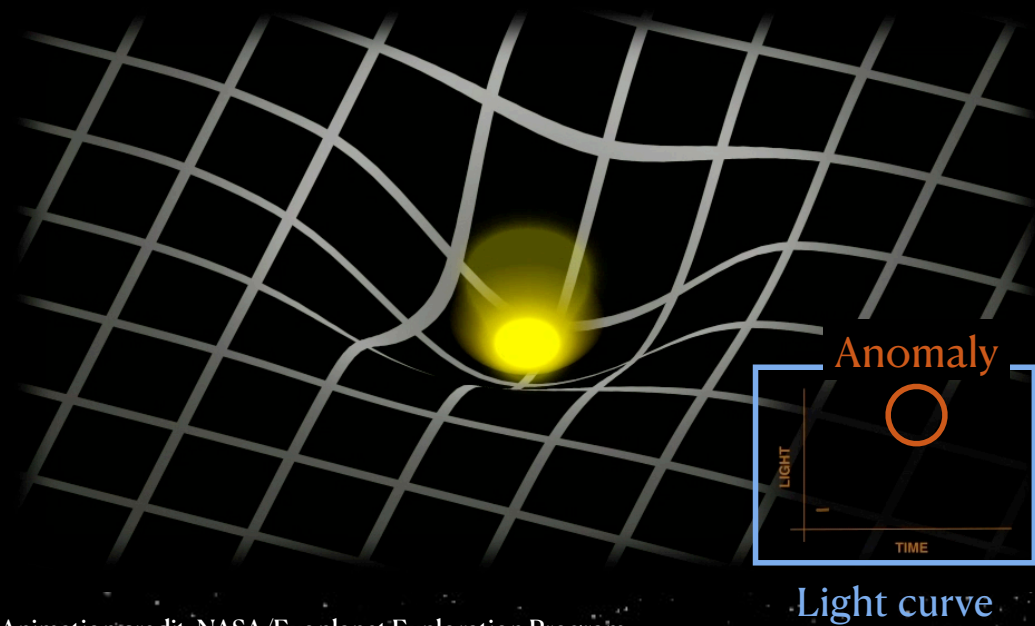




Currently: Ground-based wide field telescopes

- Traditional selection approaches:
 - Good for detecting single lens events
 - Can miss multiple lenses events
- Neural networks can be an alternative tool
 - Train with planetary and multiple lens events

Gravitational Microlensing 101



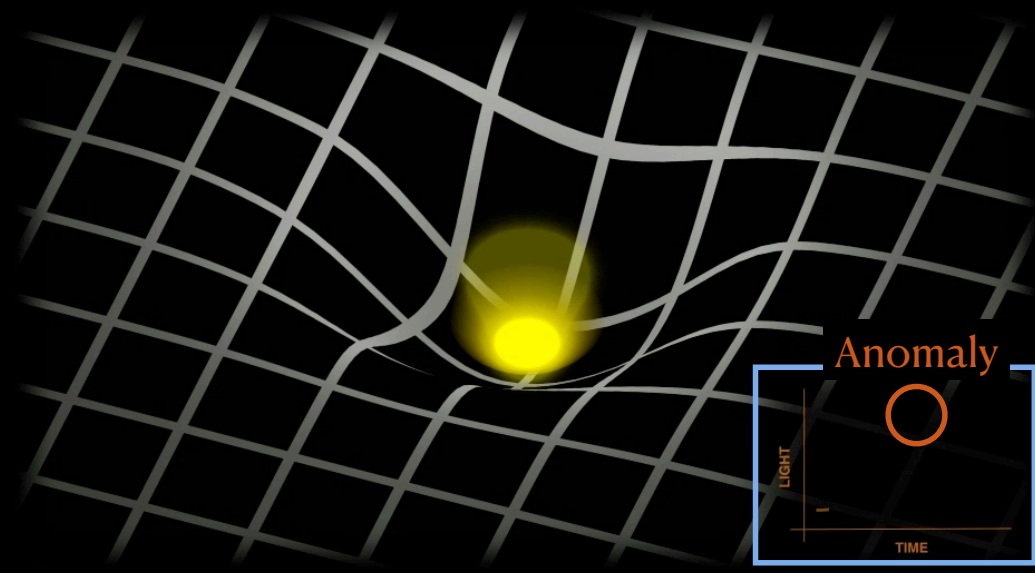
Animation credit: NASA/Exoplanet Exploration Program



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Gravitational Microlensing 101



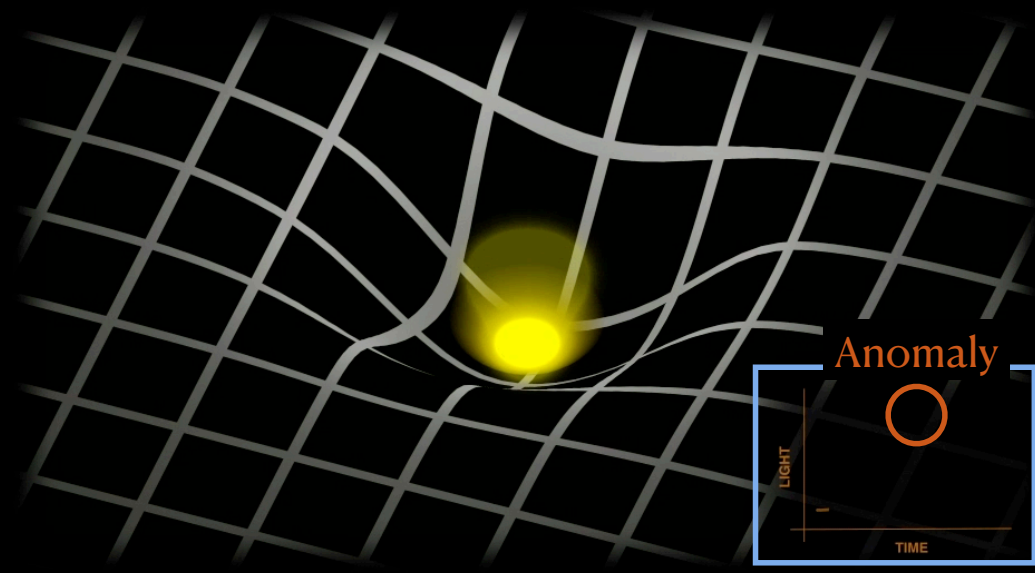
Pre-Roman: The Microlensing Observations in Astrophysics (MOA) Dataset

Light curve

Animation credit: NASA/Exoplanet Exploration Program



Gravitational Microlensing 101



Animation credit: NASA/Exoplanet Exploration Program

- Traditional selection approaches:
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Pre-Roman: The Microlensing Observations in Astrophysics (MOA) Dataset

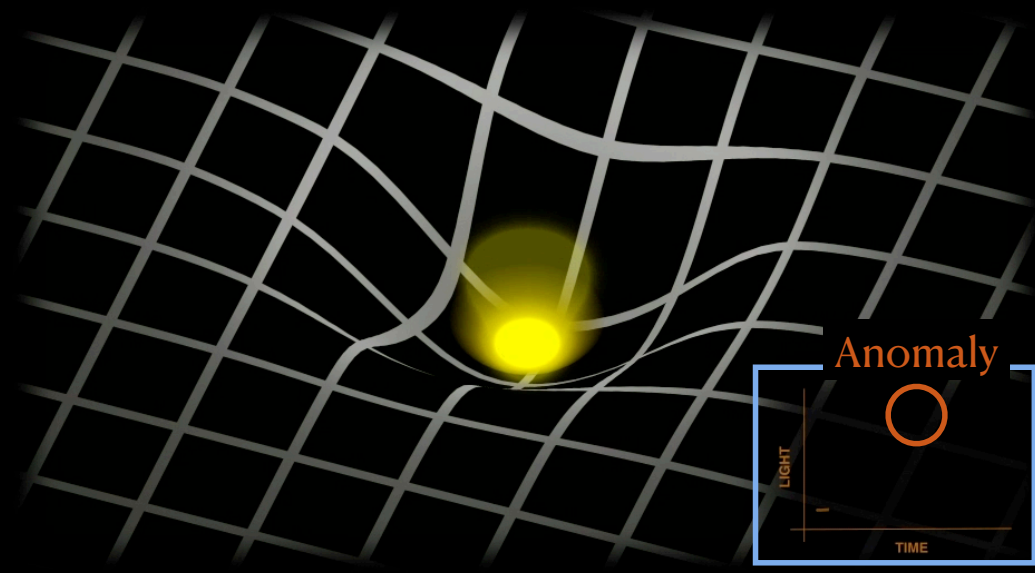
- First high cadence microlensing survey towards the Galactic bulge



Currently: Ground-based wide field telescopes

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Gravitational Microlensing 101



Pre-Roman: The Microlensing Observations in Astrophysics (MOA) Dataset

- First high cadence microlensing survey towards the Galactic bulge
- Sumi et al 2023 predicts ~21 free-floating planets per star

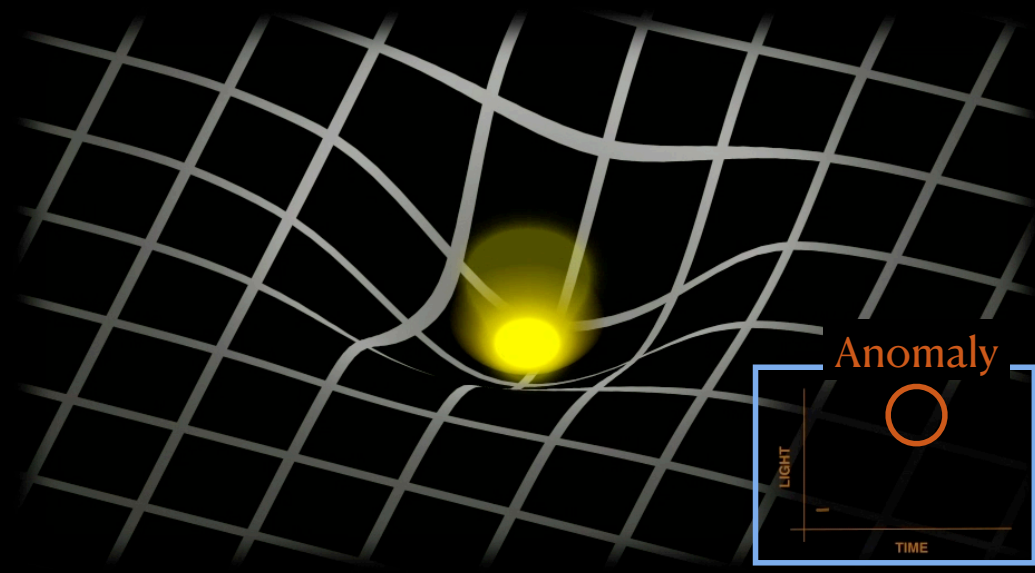
Animation credit: NASA/Exoplanet Exploration Program



Currently: Ground-based wide field telescopes

- Traditional selection approaches:
 - Good for detecting single lens events
 - Can miss multiple lenses events
- Neural networks can be an alternative tool
 - Train with planetary and multiple lens events

Gravitational Microlensing 101



Pre-Roman: The Microlensing Observations in Astrophysics (MOA) Dataset

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Light curve

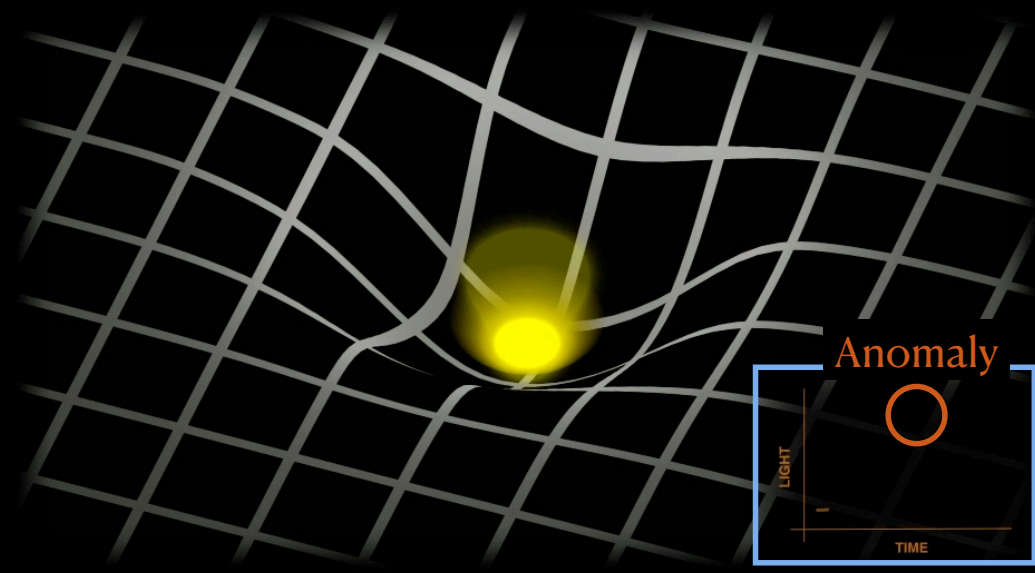
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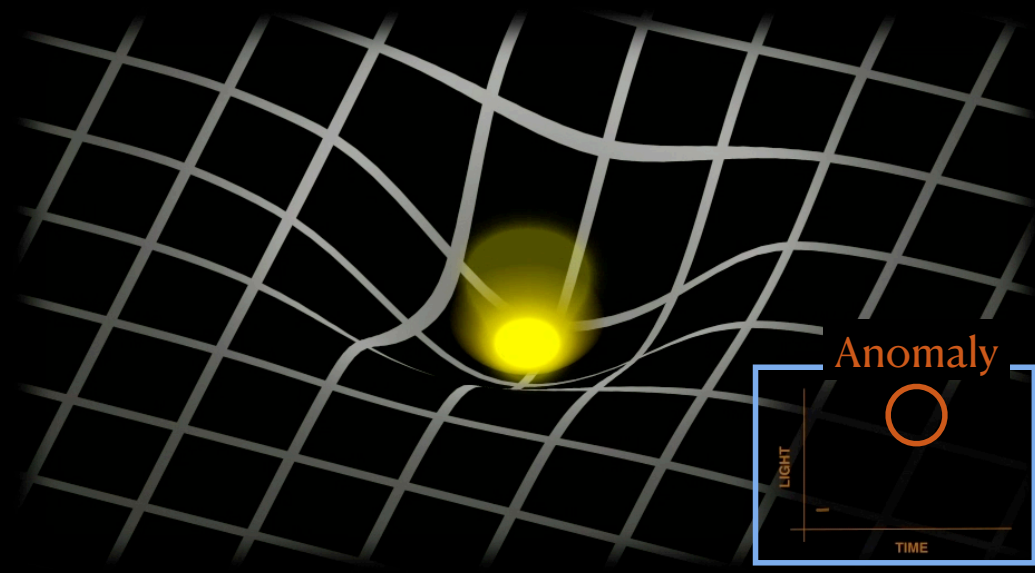
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Animation credit: NASA/Exoplanet Exploration Program

Preliminary Results

Ishitani Silva et al. in prep

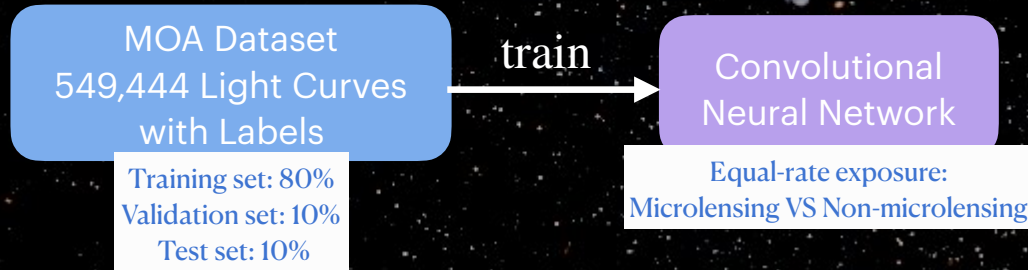
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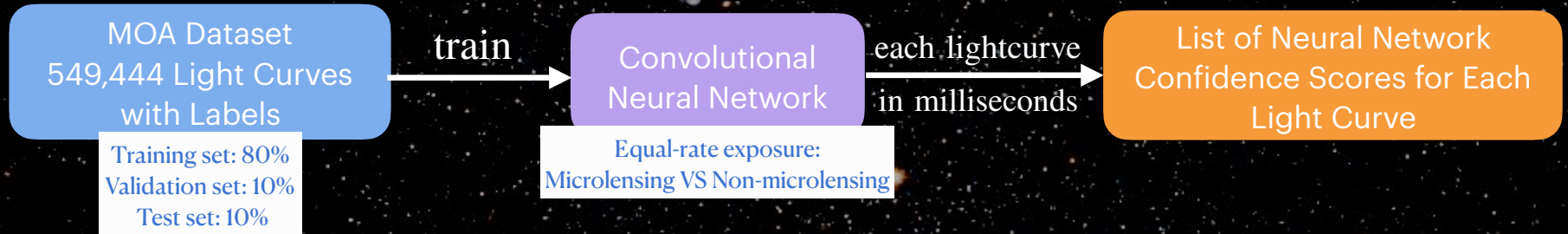
MOA Dataset
549,444 Light Curves
with Labels

Training set: 80%
Validation set: 10%
Test set: 10%

Preliminary Results



Preliminary Results



Preliminary Results

10 times - Cross-validation

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Convolutional
Neural Network

Equal-rate exposure:
Microlensing VS Non-microlensing

each lightcurve
in milliseconds

List of Neural Network
Confidence Scores for Each
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Thresholds	True positives	False positives	True negatives	False negatives
0.1	6068	150830	392509	37
0.2	6003	55592	487747	102
0.3	5930	34384	508955	175
0.4	5826	23194	520145	279
0.5	5632	14685	528654	473
0.6	5348	7895	535444	757
0.7	5122	3827	539512	983
0.8	4948	2019	541320	1157
0.9	4718	1339	542000	1387

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True label	Not Microlensing	0.9	0.1
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True label	Not Microlensing	0.99	0.015
	Microlensing	0.12	0.88
		Not Microlensing	Microlensing
		Predicted label	

Future: Two methods to measure the basic demographics of planetary systems

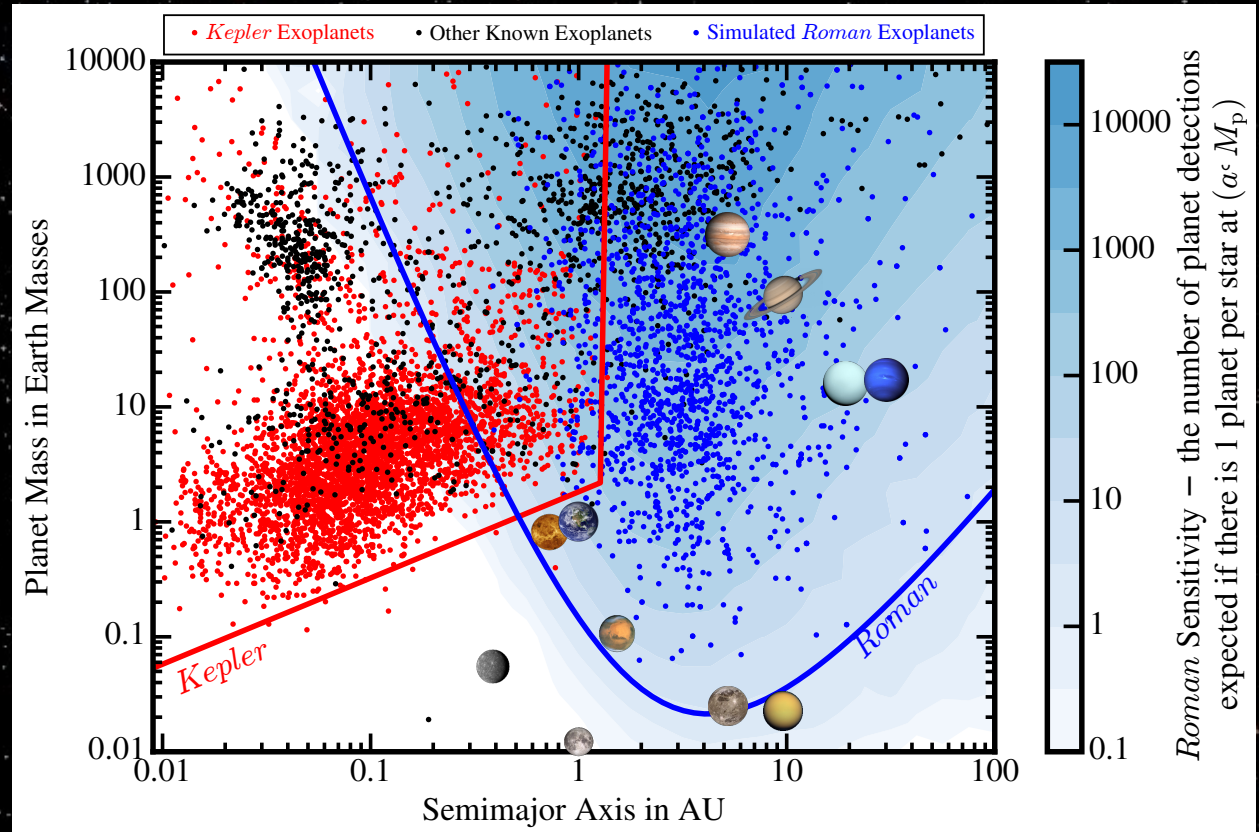
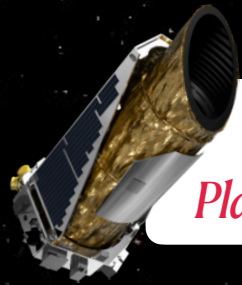


Image credit: M. Penny et al 2018

Future: Two methods to measure the basic demographics of planetary systems



Kepler
Planetary Transit

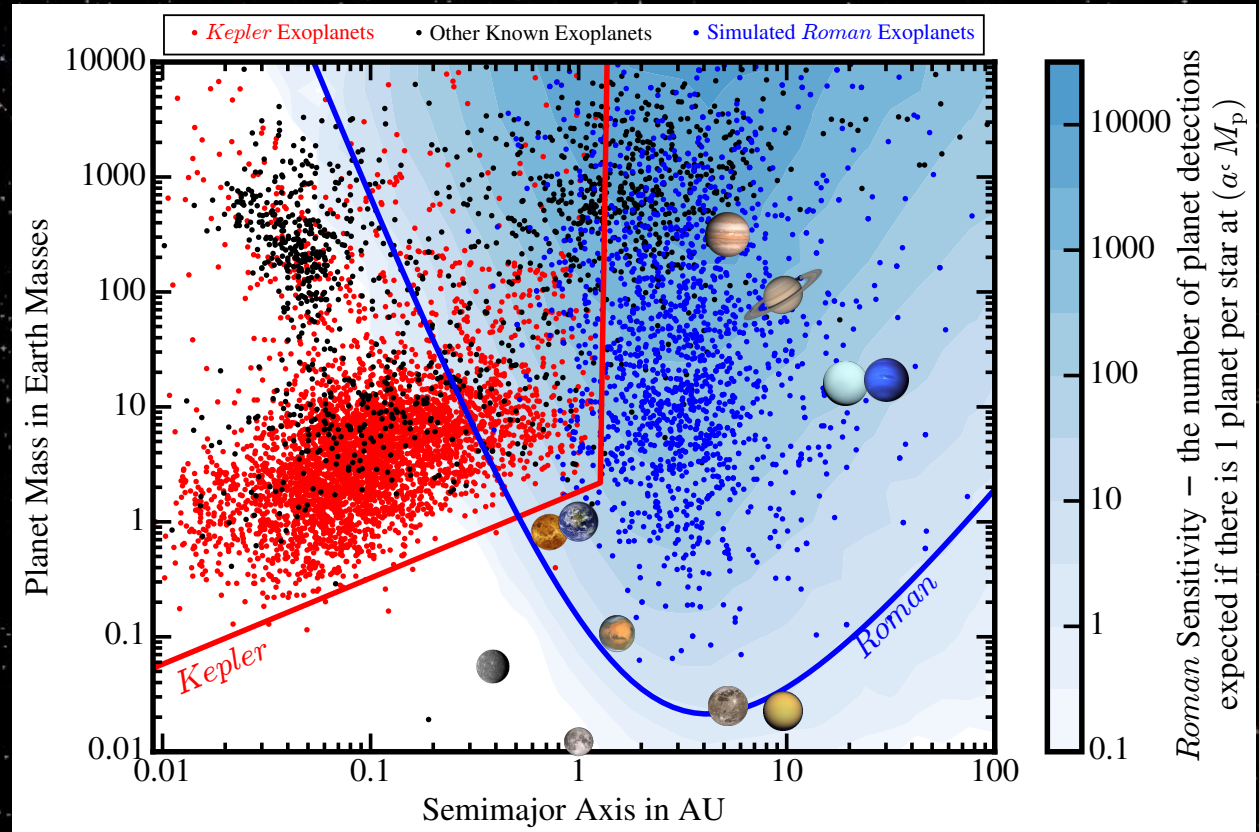
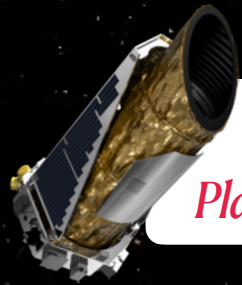
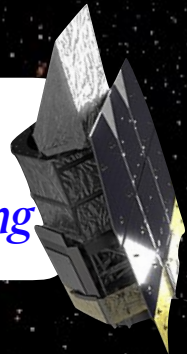


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Future: Two methods to measure the basic demographics of planetary systems



Kepler
Planetary Transit



Roman
Gravitational Microlensing

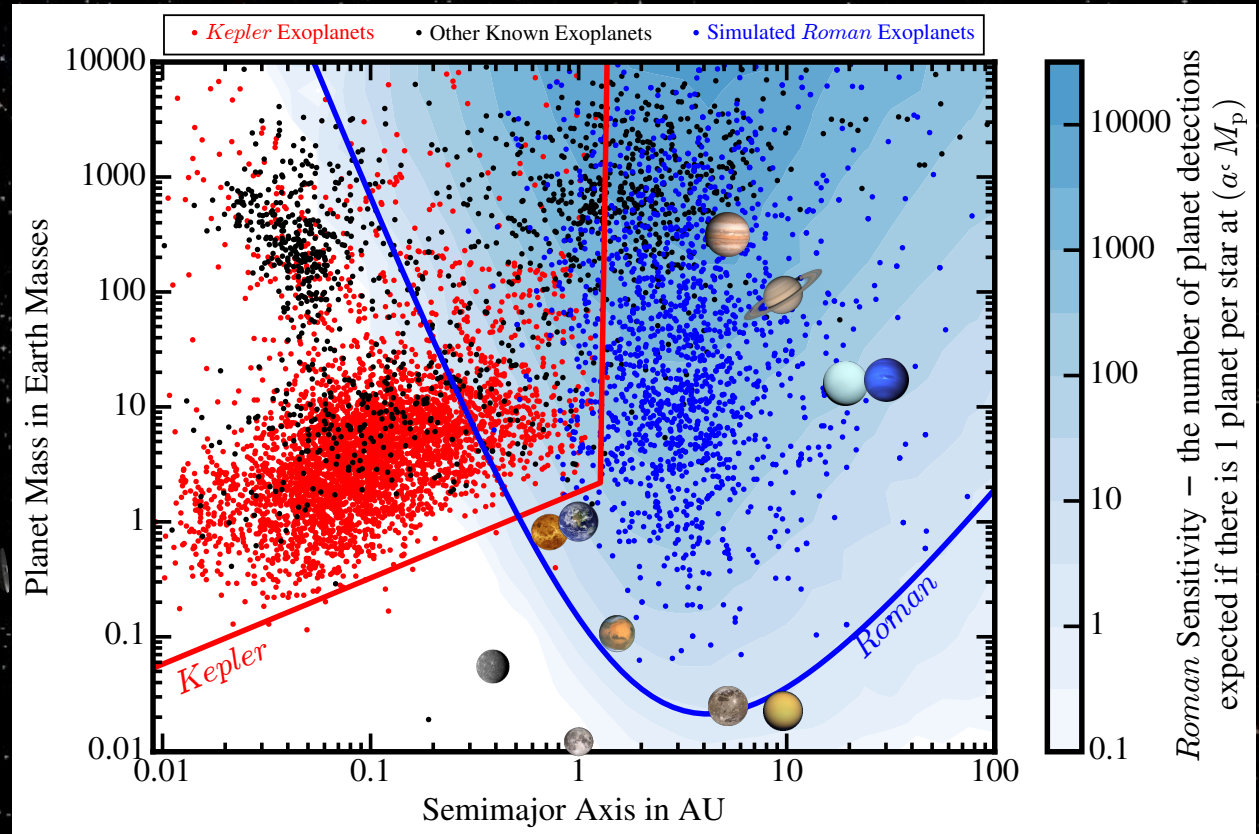
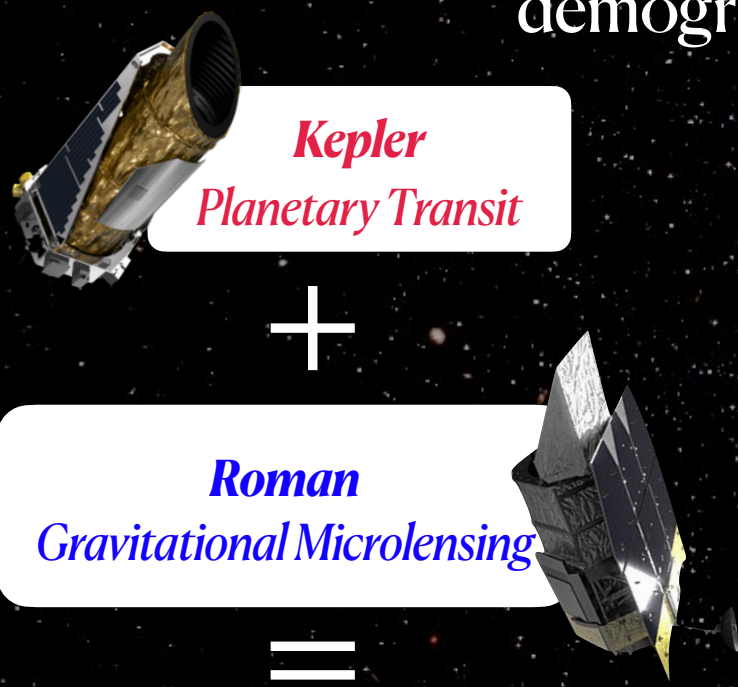
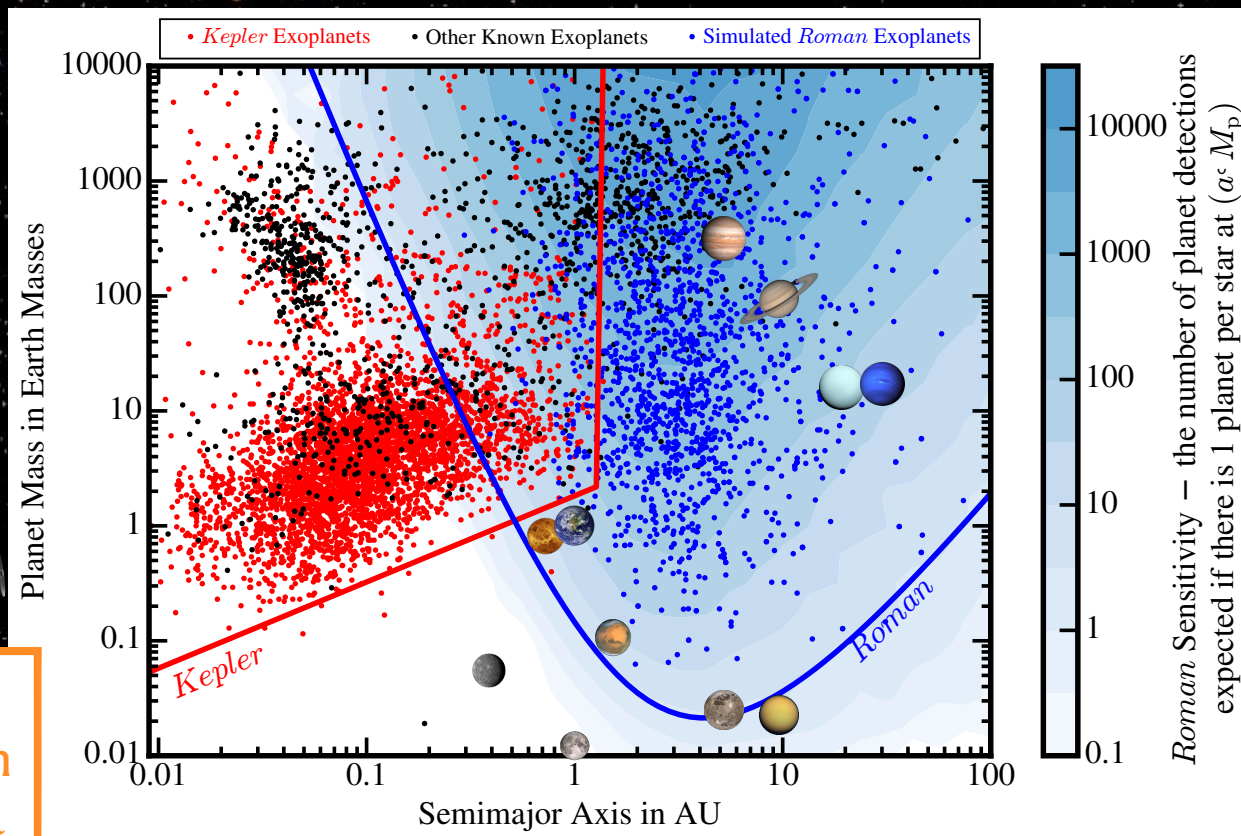


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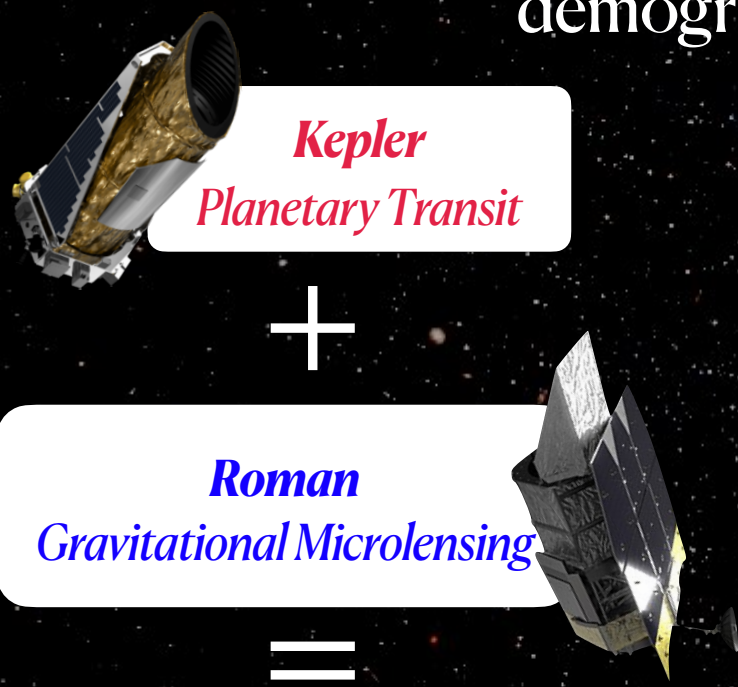
Future: Two methods to measure the basic demographics of planetary systems



The most comprehensive fundamental data on how common planets of different masses are at a broad range of orbital separations



Future: Two methods to measure the basic demographics of planetary systems



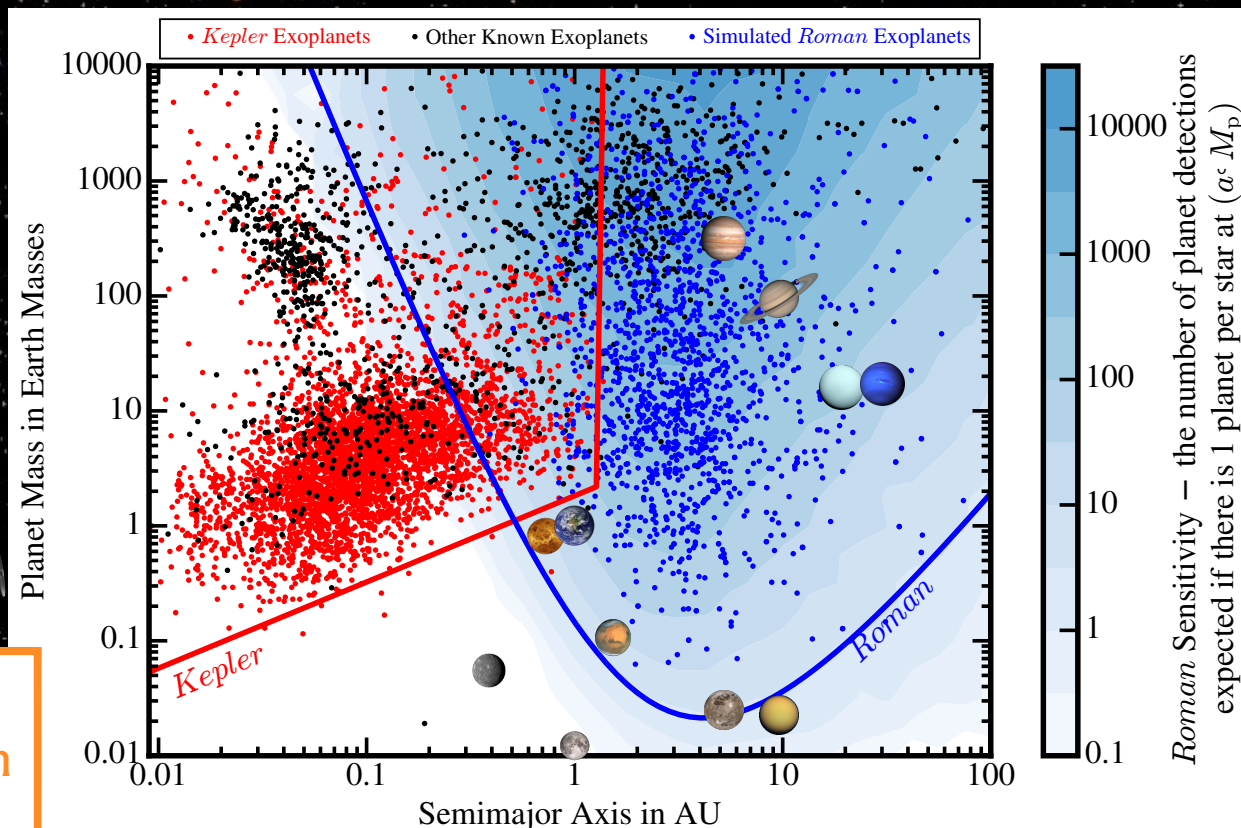
Kepler
Planetary Transit

+

Roman
Gravitational Microlensing

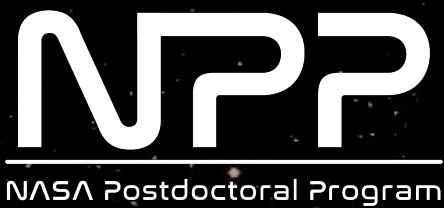
=

The most comprehensive fundamental data on how common planets of different masses are at a broad range of orbital separations



Neural networks can help us detecting these planets!

NASA



Thank you!

Questions?

Back Up Slides

Our Neural Network Pipeline

