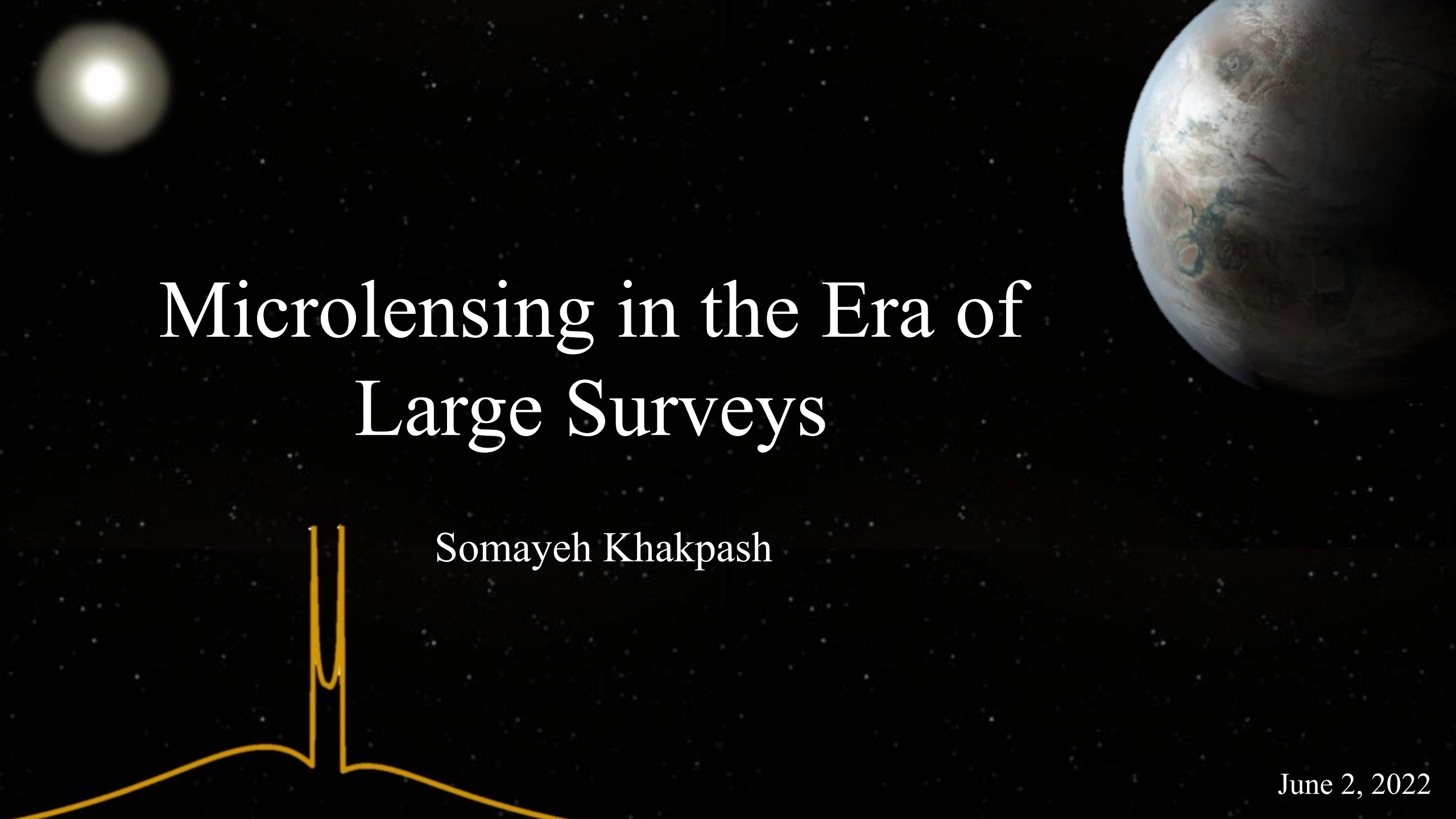

Microlensing in the Era of Large Surveys

Somayeh Khakpash

June 2, 2022

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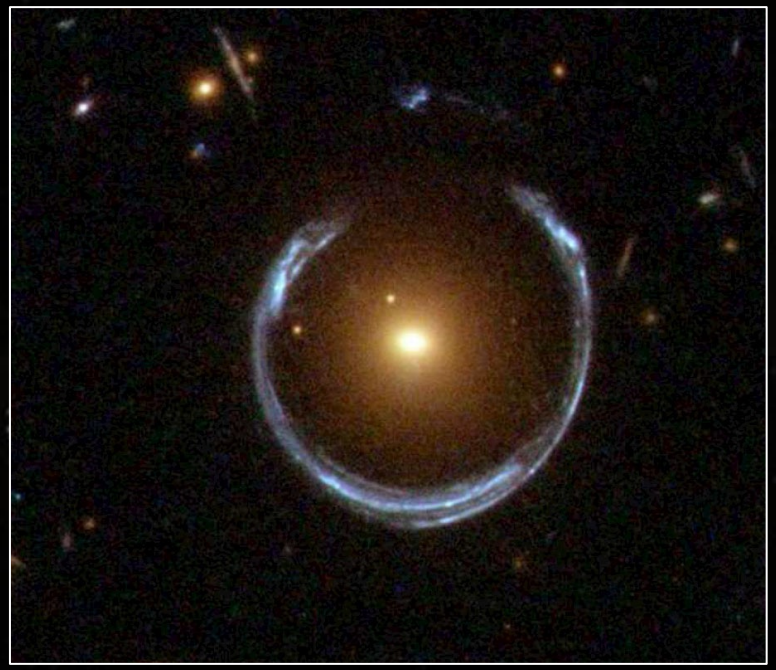
What is Microlensing?

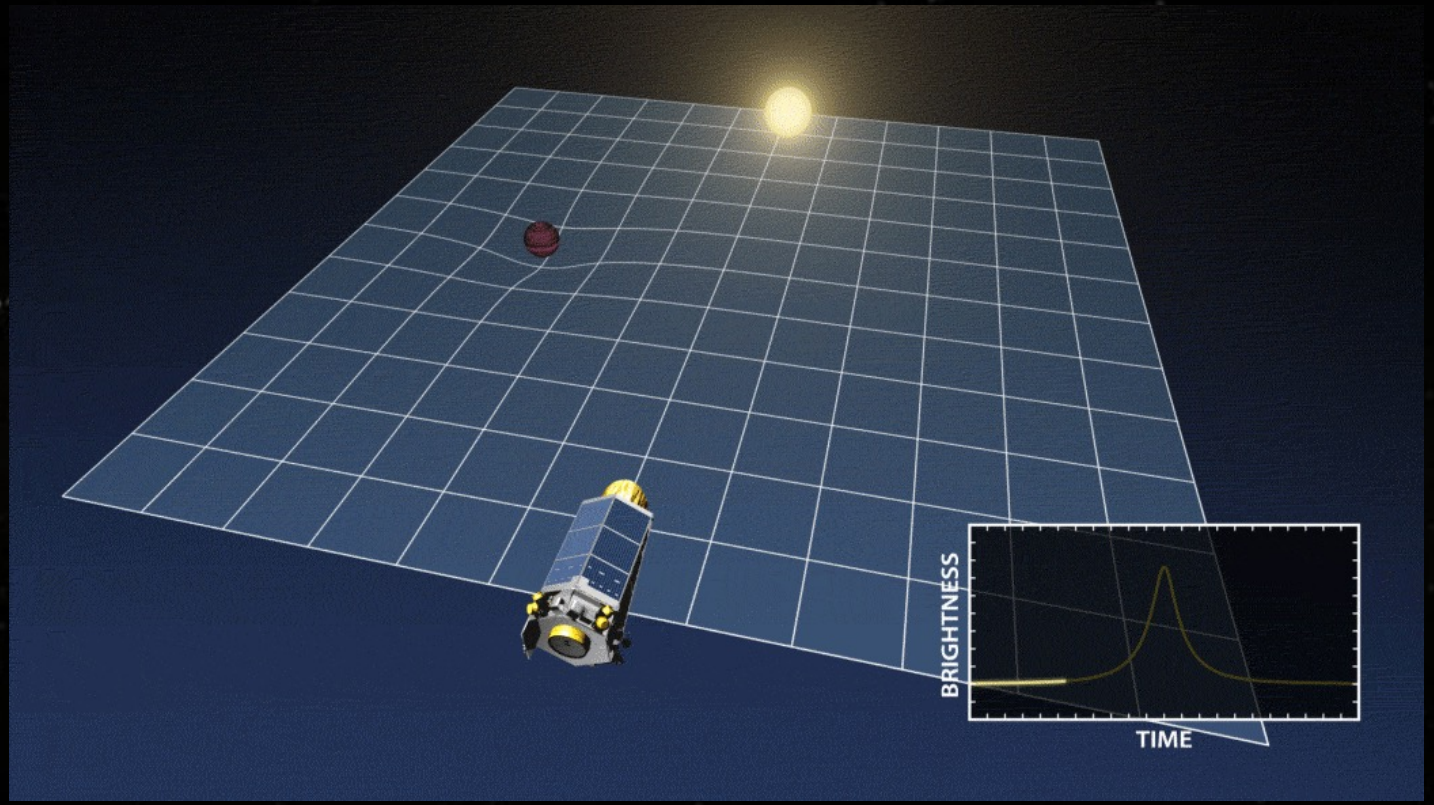
Introduction to Microlensing

Gravitational Lensing



Introduction to Microlensing

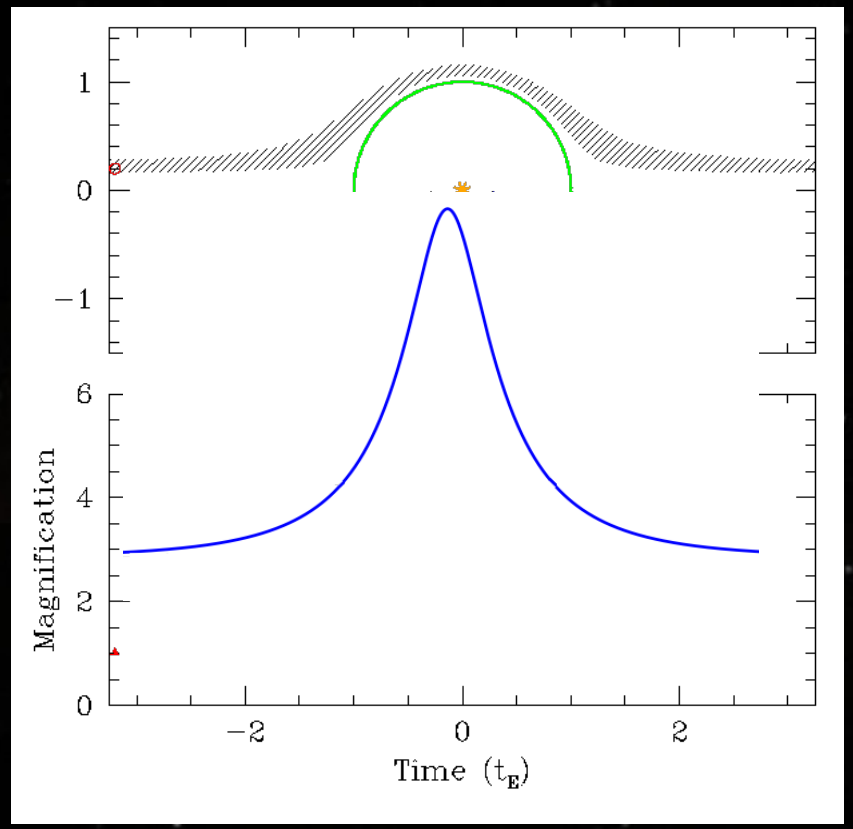
Gravitational Microlensing



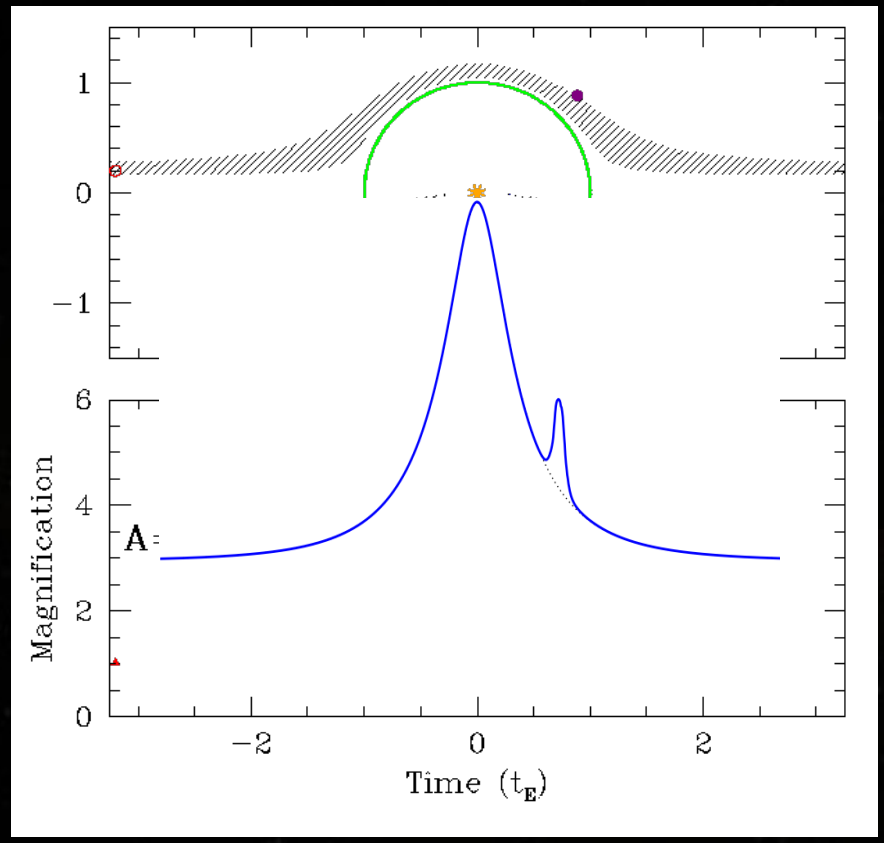
https://www.jpl.nasa.gov/news/news.php?feature=6314

Introduction to Microlensing

Single Lens



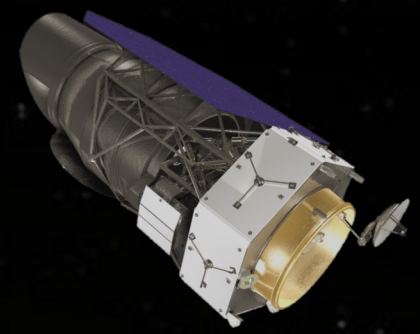
Planetary System Lens

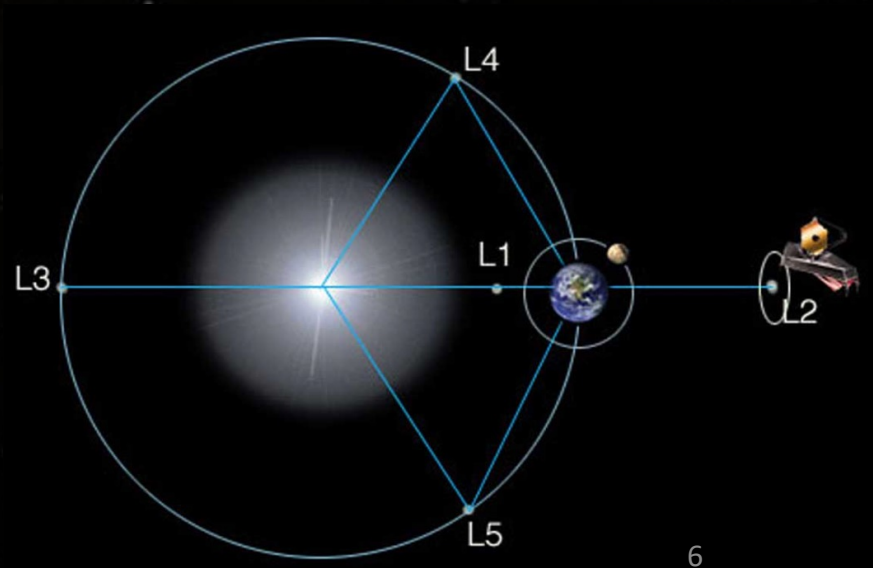


Animations by Scott Gaudi

The Roman Space Telescope

- NASA's mission expected to be launched mid 2020's
- 2.4 meters Infrared telescope with a field of view of 100 times greater than that of the Hubble.
- Will be located at Earth-Sun L2 point
- Main Scientific goals:
  - Discovering the nature of Dark Matter
  - Microlensing Exoplanets
  - Study far galaxies





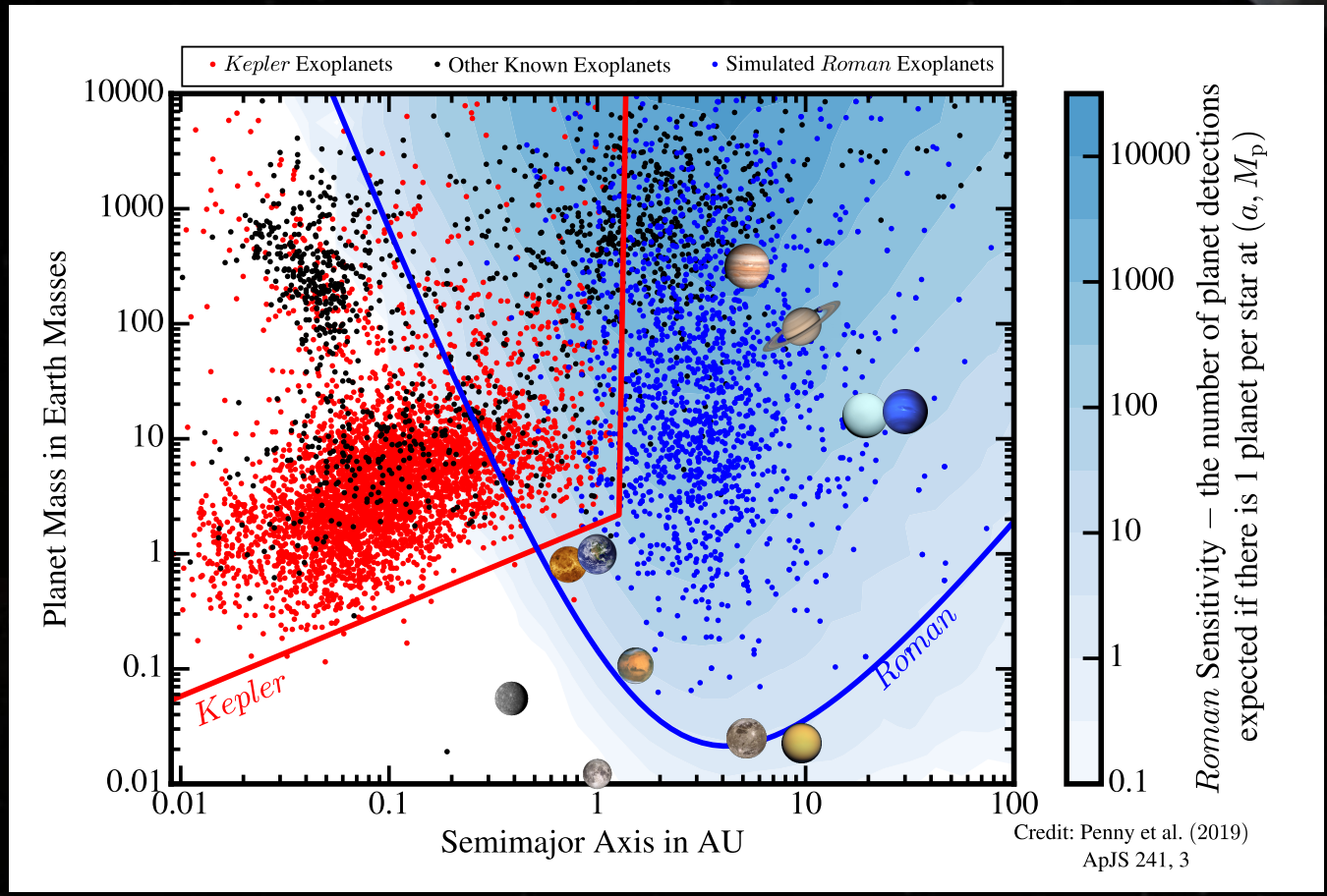
https://solarsystem.nasa.gov/resources/754/what-is-a-lagrange-point/

The Roman Space Telescope

- The microlensing survey will take place during six 72-day long seasons spread through the mission's lifetime of 5 years.
- It will observe the galactic bulge with a 15 minute cadence.
- It will observe about 10^8 stars and discover ~54,000 microlensing events and is expected to discover about 1400 planets.

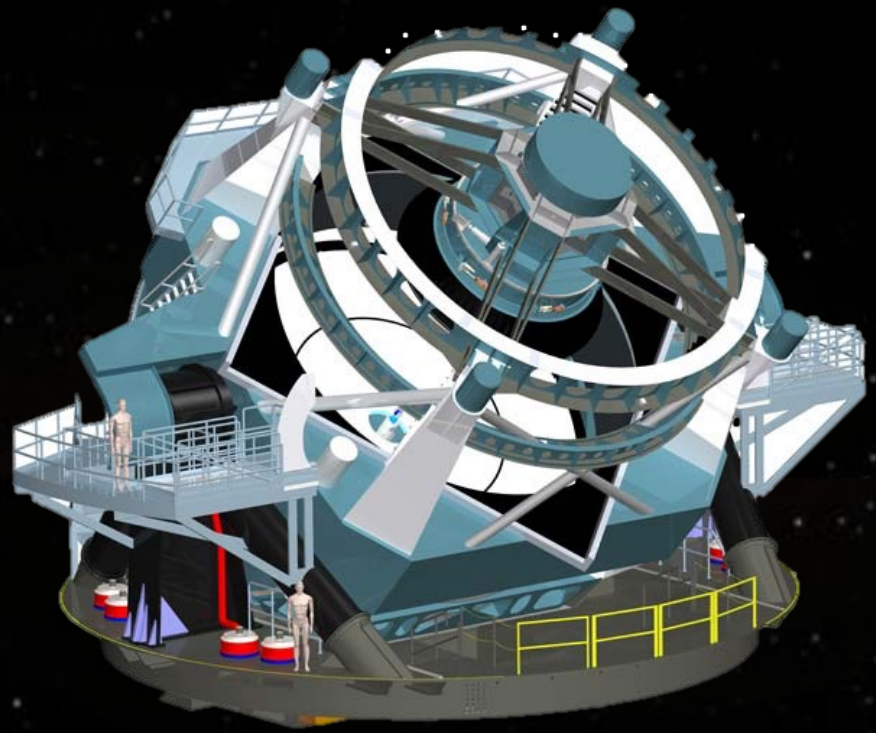
Why Roman is important?

- We are interested to compare population of the detected exoplanets with predicted models.
- Roman capabilities would allow probing new regions of the parameter space.



Vera C. Rubin Legacy Survey of Space and Time

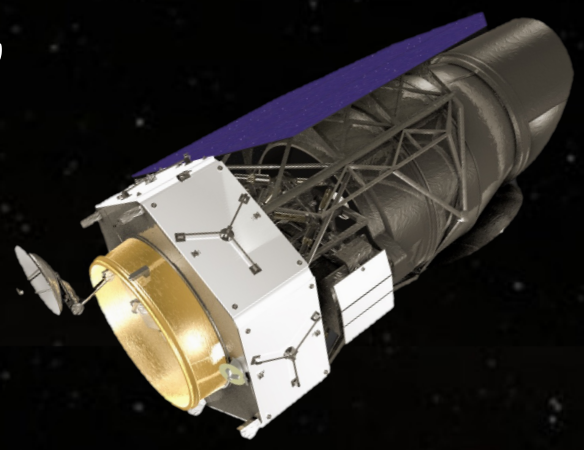
- All-sky ground-based telescope located in Chile
- Covers the southern sky in 10 years
- Has four main science drivers:
  - Probing dark energy and dark matter.
  - Taking an inventory of the solar system.
  - Exploring the transient optical sky.
  - Mapping the Milky Way.



Roman & Rubin

Near Infrared

High Cadence



Inter-seasonal gaps

Located at L2

ugrizy

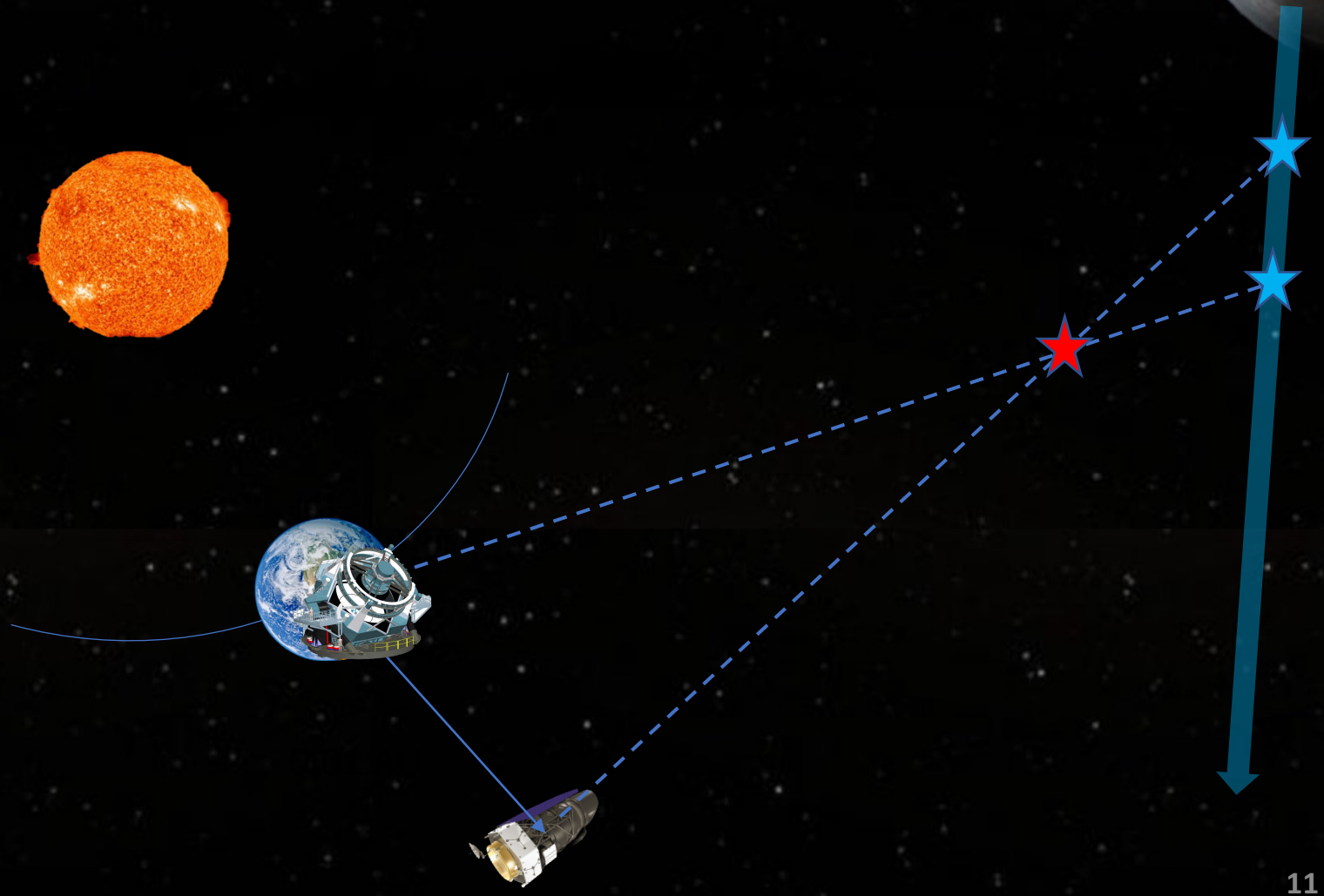
10-year survey

Low Cadence

Limited Visibility

Roman & Rubin: Satellite Parallax

- Measuring the microlensing parallax allows characterizing the lens system.
- Roman-Rubin separation of 0.01 AU is ideal for parallaxes of free-floating planets



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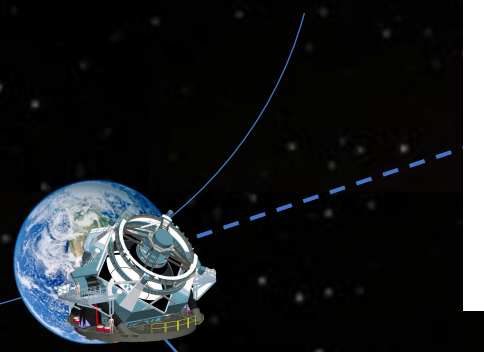
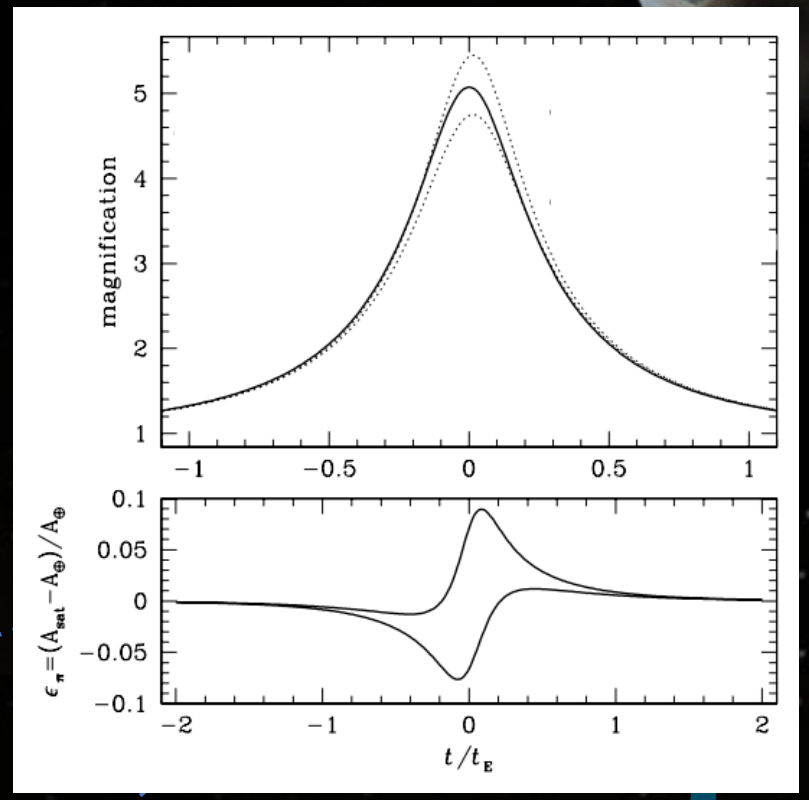
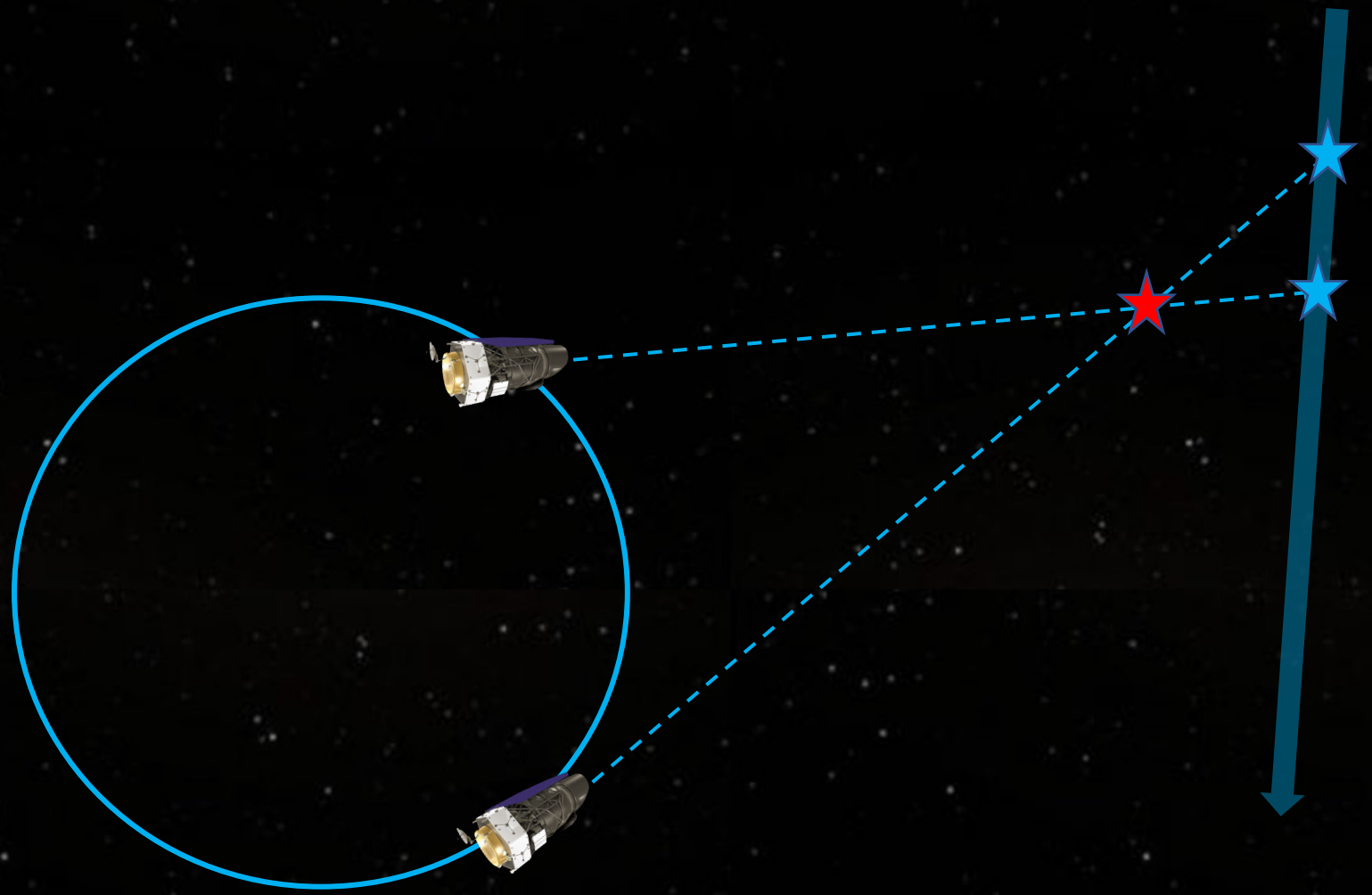
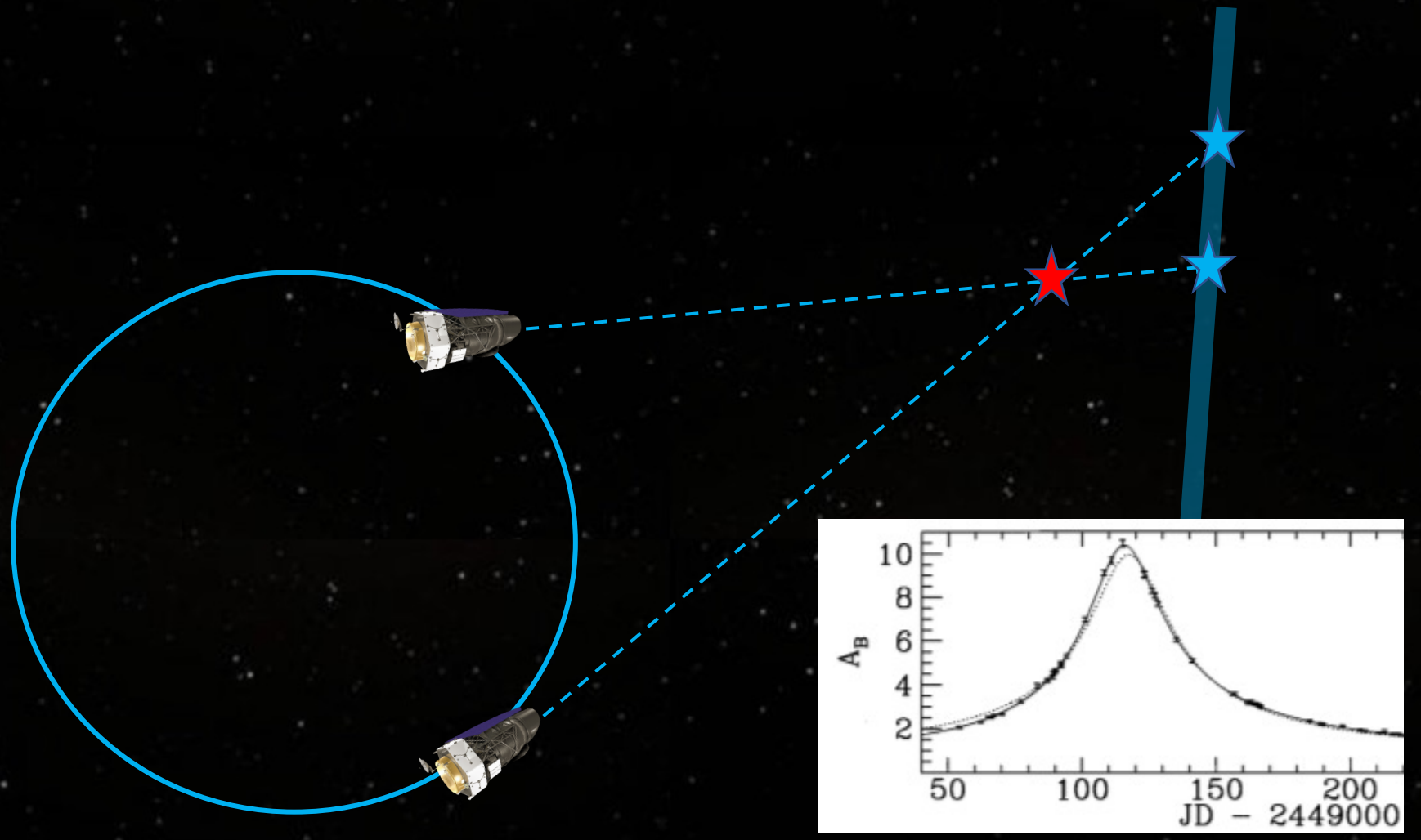




Roman & Rubin: Orbital Parallax



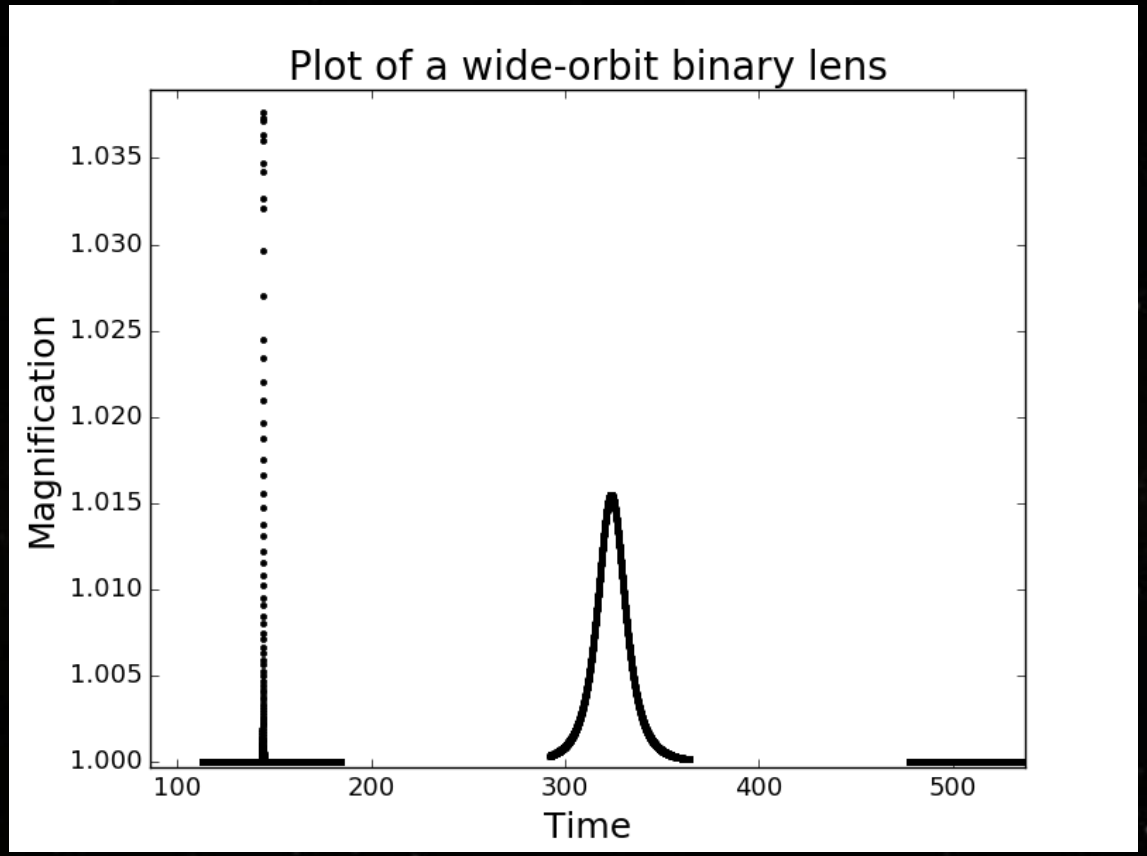
Roman & Rubin: Orbital Parallax



Alcock 1995

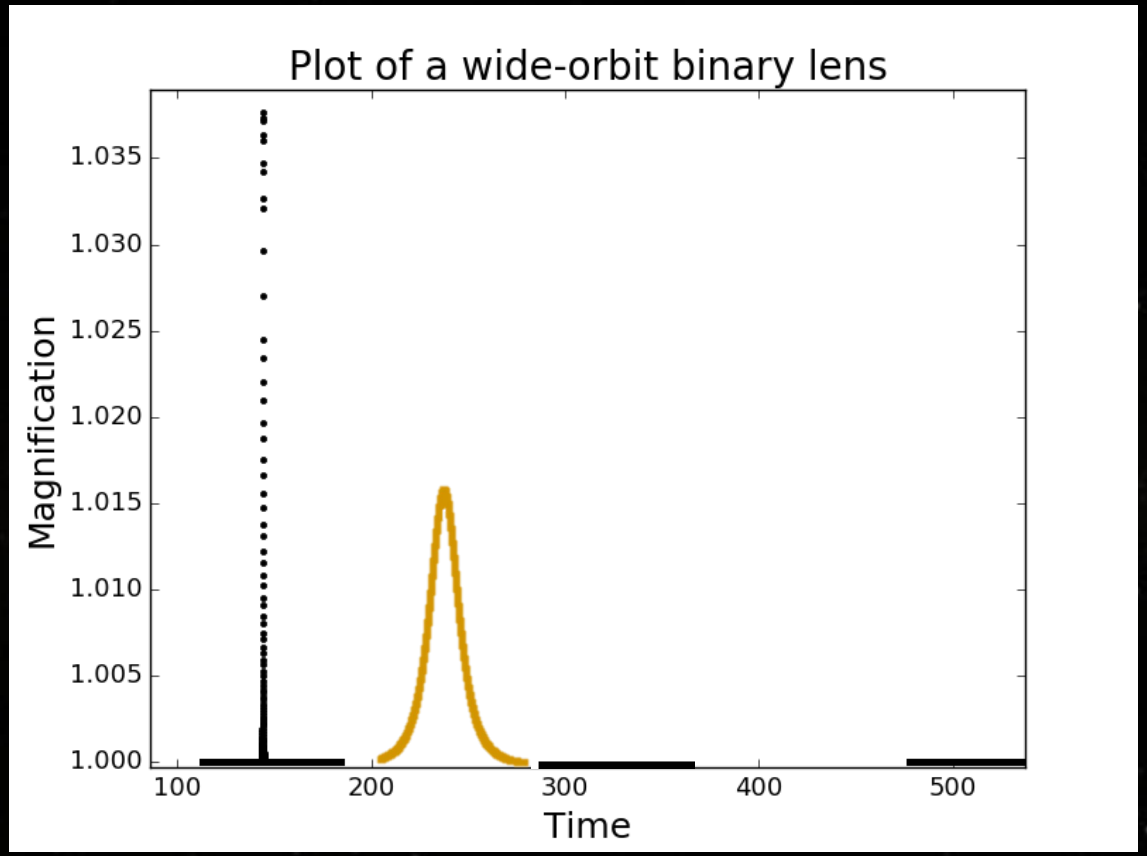
Roman & Rubin: Coverage

Wide-orbit planets



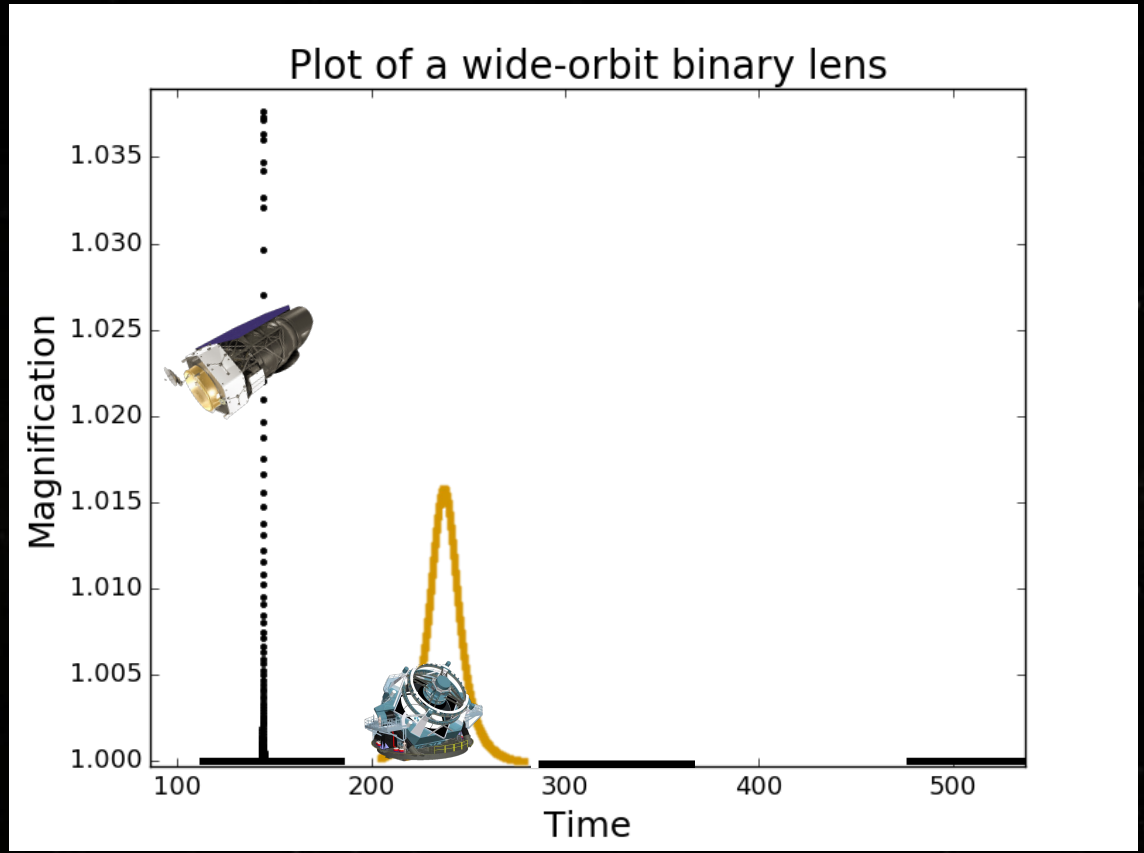
Roman & Rubin: Coverage

Wide-orbit planets



Roman & Rubin: Coverage

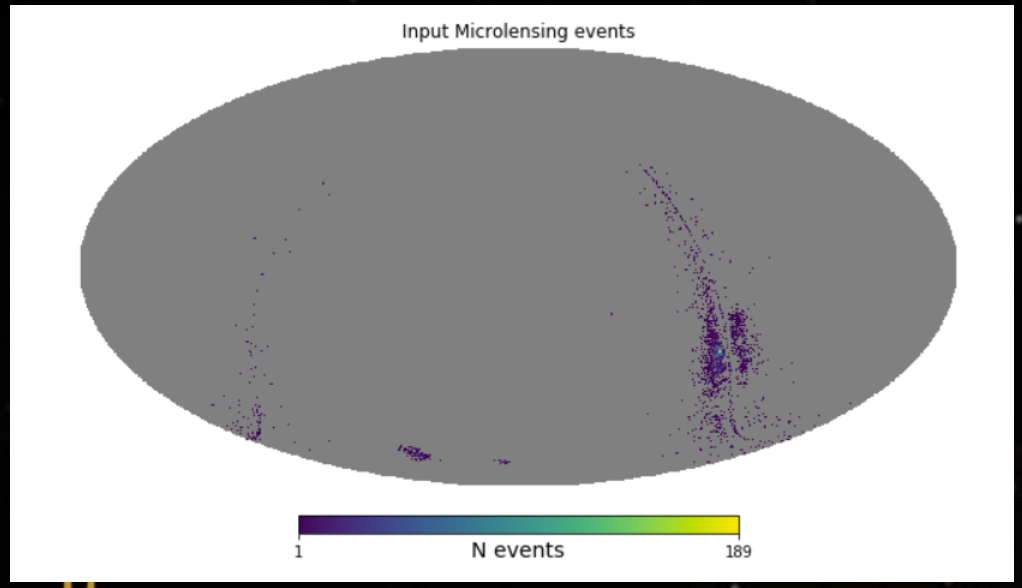
Wide-orbit planets

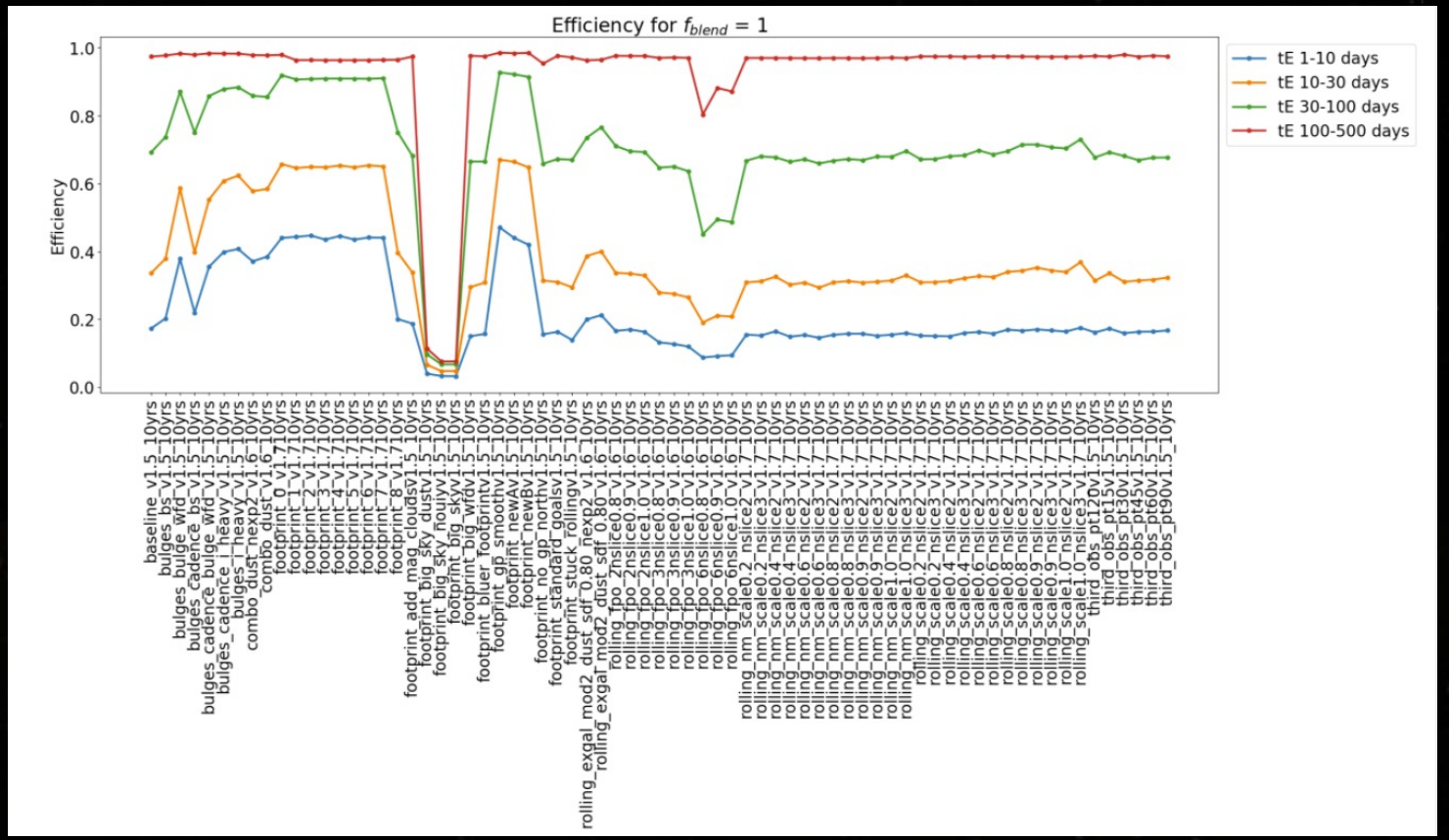


Rubin LSST TVS Science Collaboration: Microlensing Subgroup

- Writing White papers to show the impact of Rubin on microlensing science.
- Writing the microlensing metric to evaluate Rubin survey strategy simulations on detection and characterization of microlensing events.
- Providing feedback for the survey strategy committee on the performance of new simulations

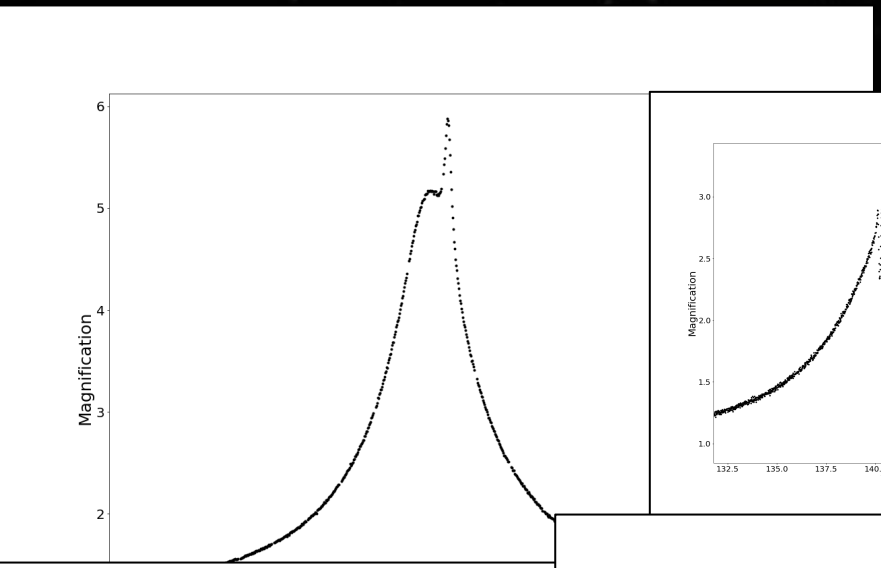
Rubin LSST TVS Science Collaboration: Microlensing Subgroup

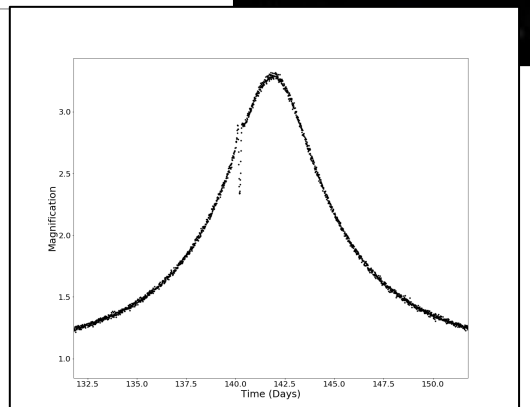


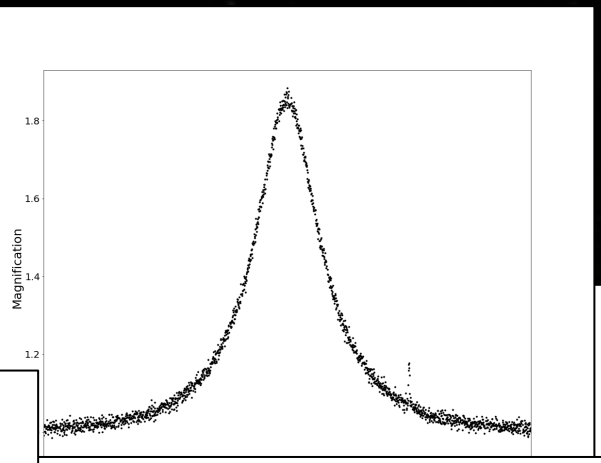


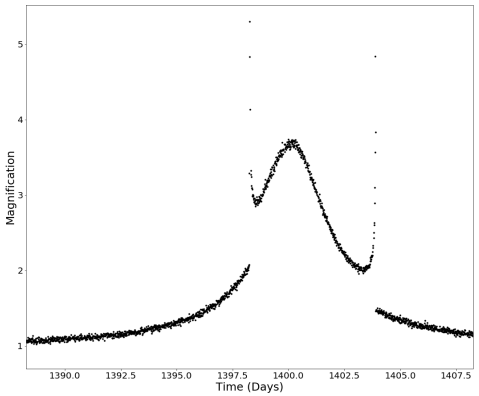
Credit: Natasha Abrams, Markus Hundertmark, and the rest of the microlensing subgroup

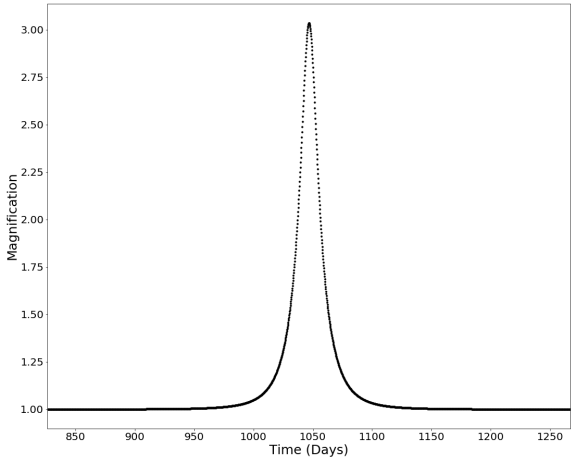
Detecting and Classifying Microlensing Light Curves

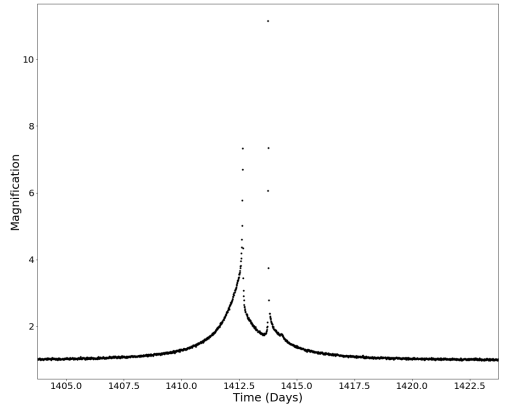


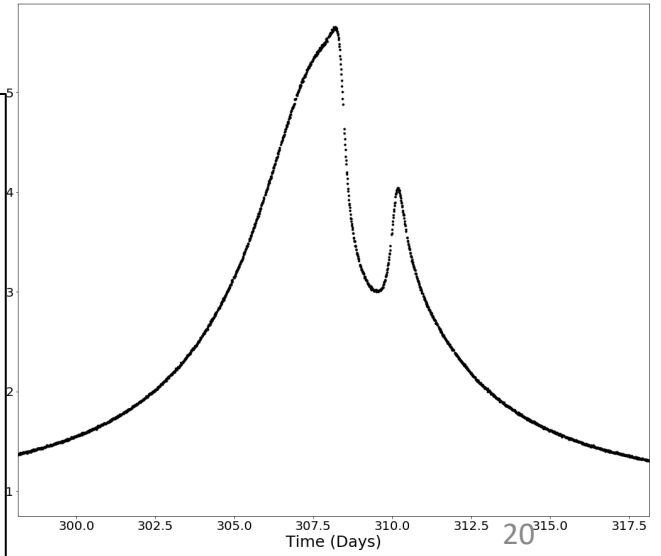












Discussing a Challenge

- Fully analyzing double-lens light curves requires significant investment of human and computing resources.
- Large surveys release huge amount of data on a daily basis.
- We need to analyze light curves quickly to find out what kind of systems they have.
- If we have planetary system candidates, we need to schedule rapid follow-up observations.

Solution to a Challenging Problem

Problem: Given the large number of light curves that need to be searched and the need for scheduling follow-up observations, methods that can quickly classify and characterize planetary microlensing events are valuable.

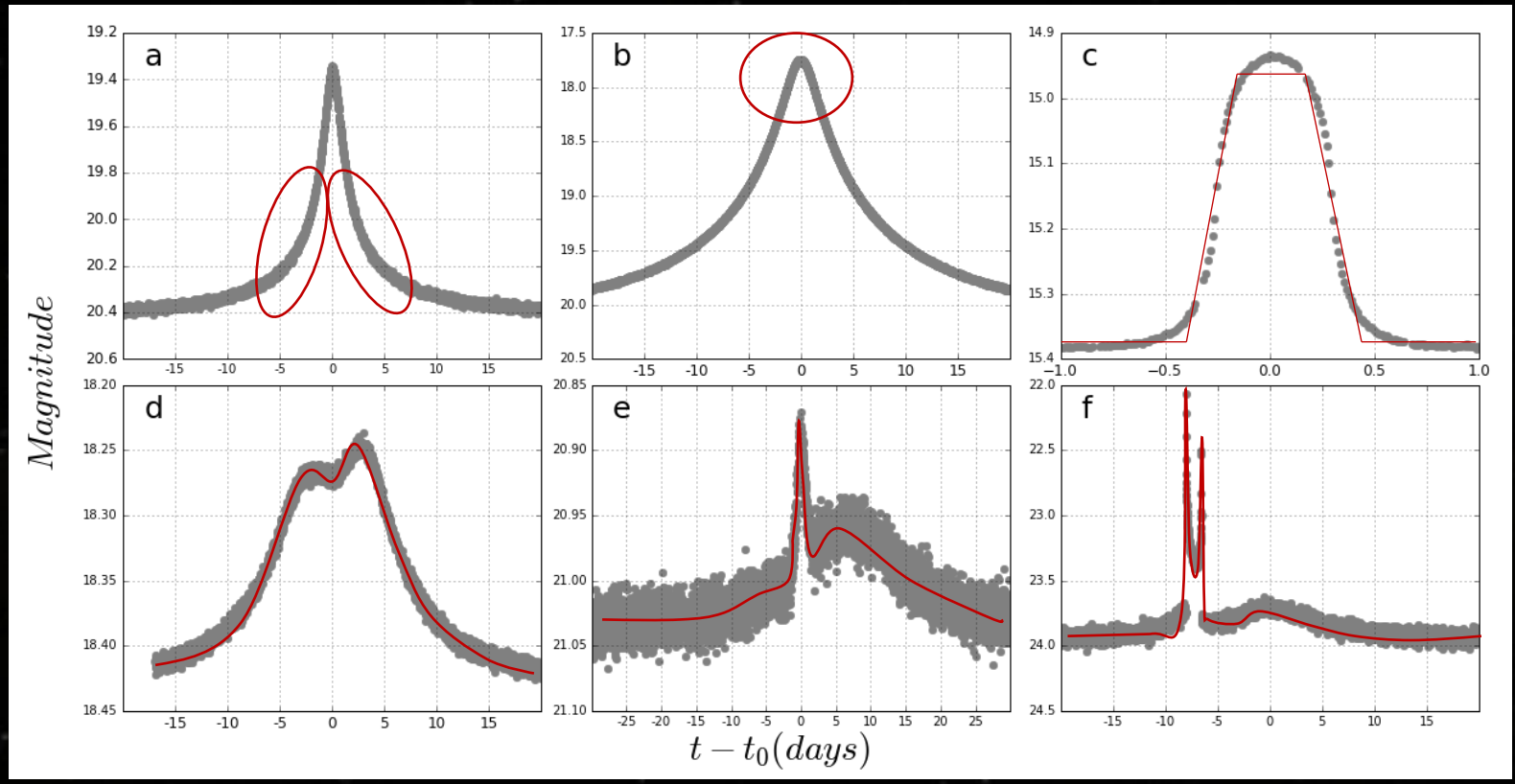
Solution: Machine learning algorithms are often used in astronomy for classifying time series, spectra, and images. Applying machine learning to classify different types of microlensing light curves using morphological features is a new approach and needs to be investigated.

Summary of the Features to be Extracted

- We fit various functions to the peak of the light curves and measure different properties of them such as number of deviations from the peak, time of the deviations, symmetry of the main peak, smoothness of the peak, and quantities like the duration and height of the peaks.
- Each feature contains information about the light curve and a combination of them can help classify the light curves.

Microlensing Models and their Features

- Point-source Point-lens (PSPL) model
- Determining symmetry
- Cauchy Distribution Fit
- Trapezoidal Function Fit
- Chebyshev Polynomials Fit
- PSPL+busy Function Fit

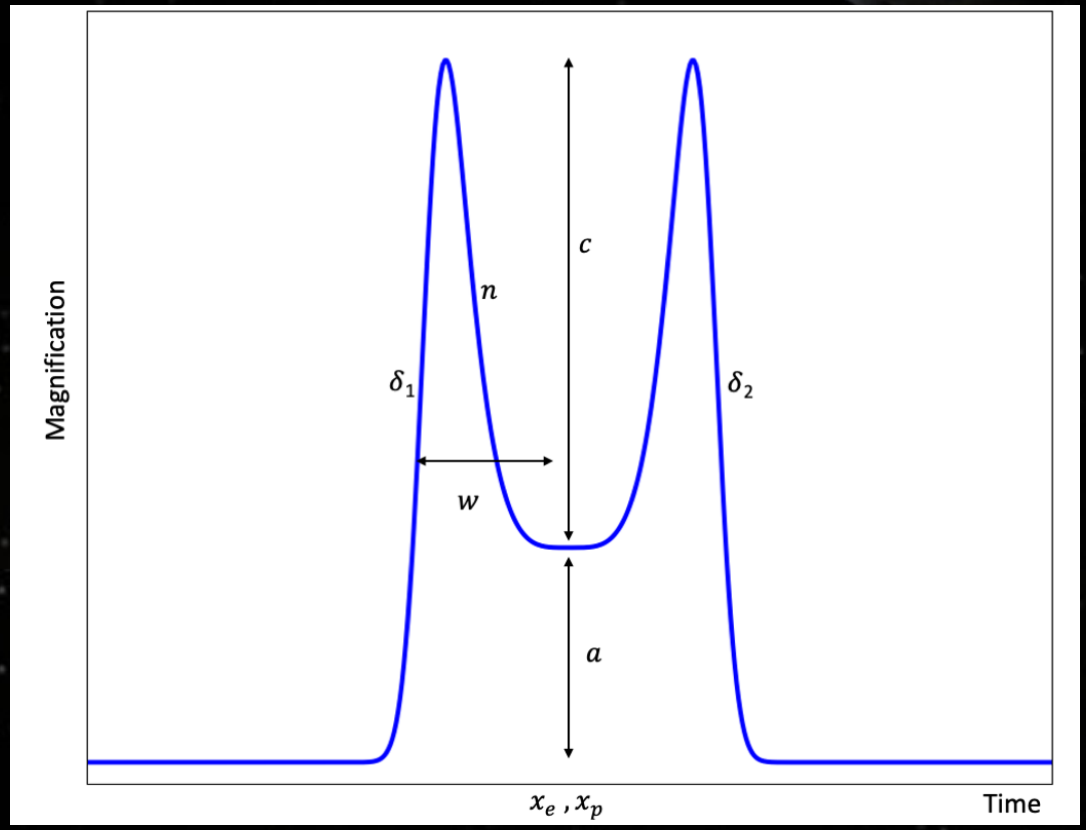


Khakpash et al. in prep.

Planetary Parameter Finder

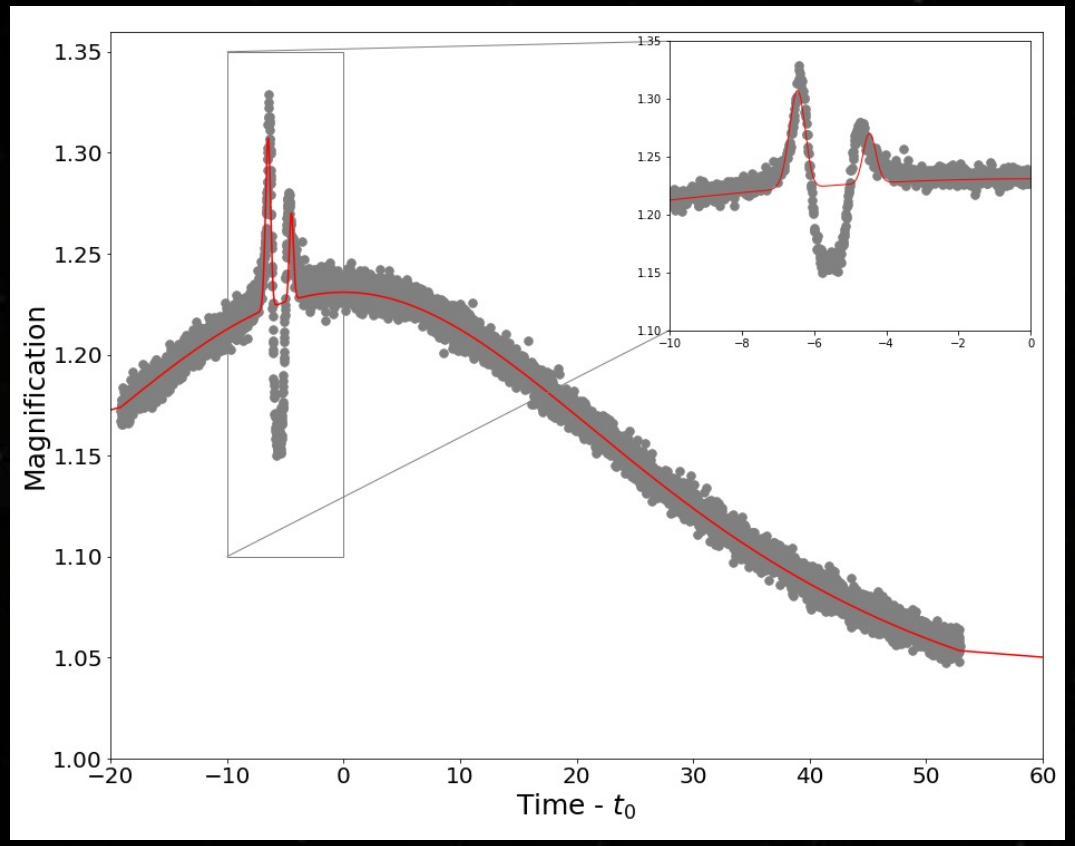
- Our goal is to find physical parameters, s and q, of the planetary systems without having to fully analyze them.
- We use the busy function to fit to both non-caustic-crossing and caustic-crossing events.
- The busy function is:

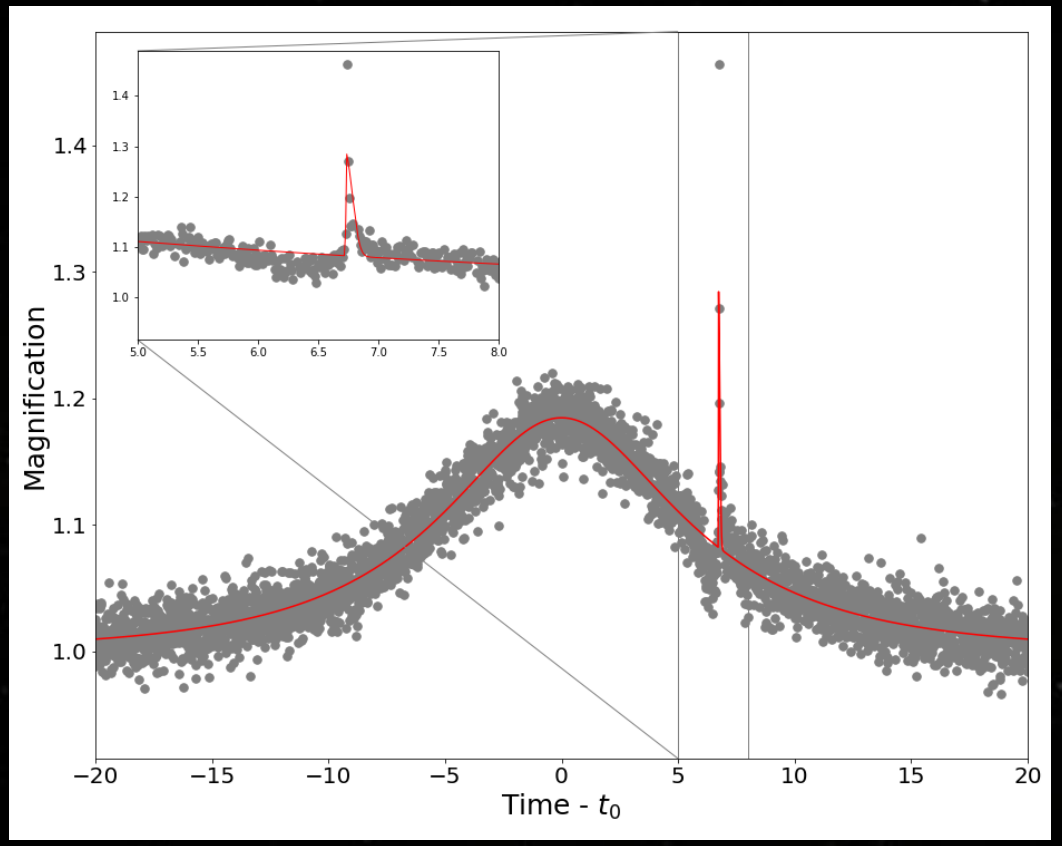
$$A(t) = \left({}^{a}/_{2}\right)\times\left(\mathrm{erf}\left(\delta_1(\omega + \epsilon t - x_e)\right) + 1\right) \times\left(\mathrm{erf}\left(\delta_2(\omega + \epsilon t - x_e)\right) + 1\right) \times\left(c\times\left|\epsilon t - x_p\right|^{n} + 1\right)$$



Westmeier et. Al. 2014

Planetary Parameter Finder - Results



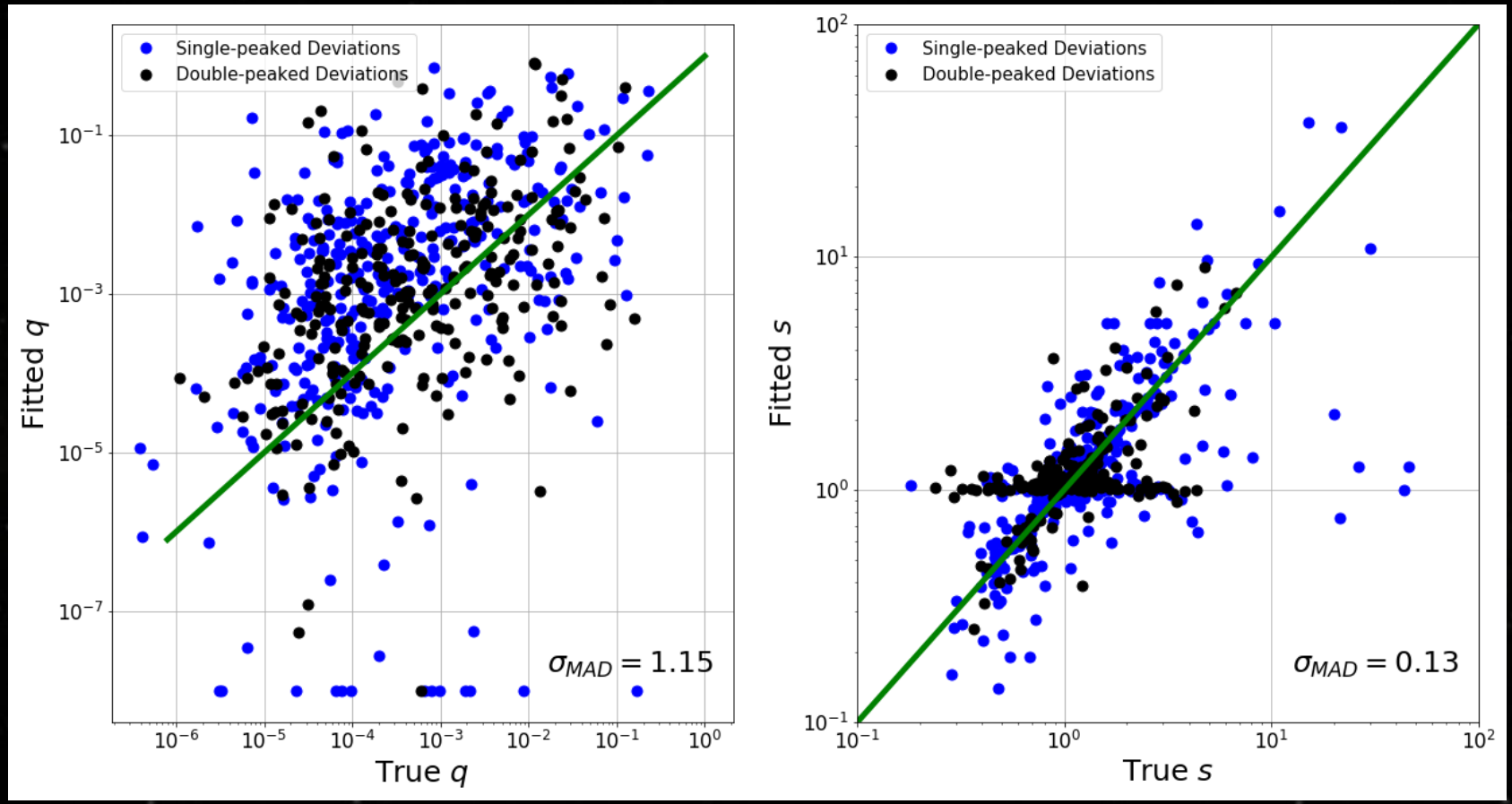


Khakpash et. Al. 2021

Planetary Parameter Finder - Results

Mass Ratio

Projected Separation



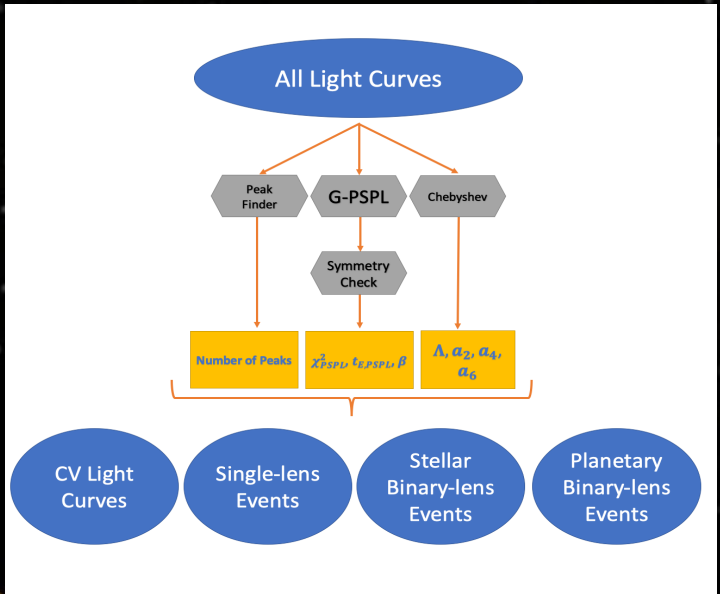
Khakpash et. Al. 2021

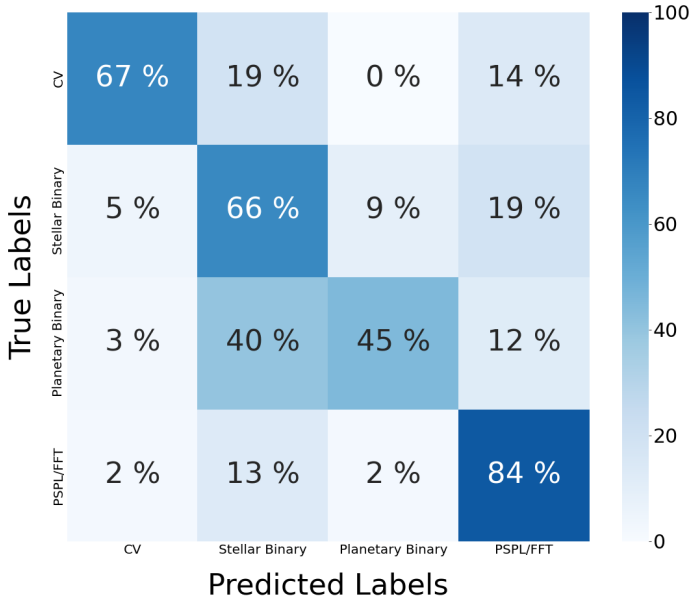
Summary of the Extracted Features

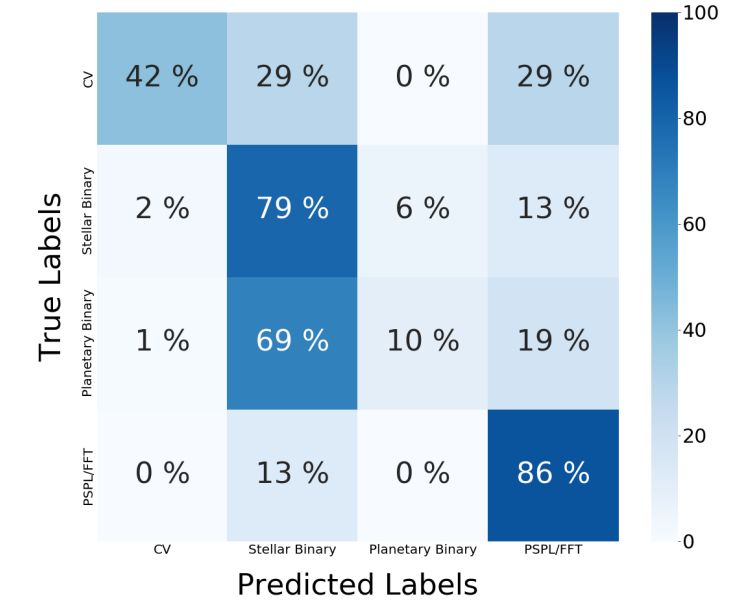
Algorithm	Features
Peak Finder	Number of Peaks
G-PSPL Fit	$\chi^2_{G-PSPL}, t_{E,G-PSPL}$
Symmetry Check	β
Trapezoidal Function Fit	$\kappa, \Delta\tau_{full}$
Cauchy Distribution Fit	ψ, b
Planetary Parameter Finder	$s, q, \chi^2_{PSPL}, t_{E,PSPL}$
Chebyshev Polynomial Fit	Λ, a_2, a_4, a_6

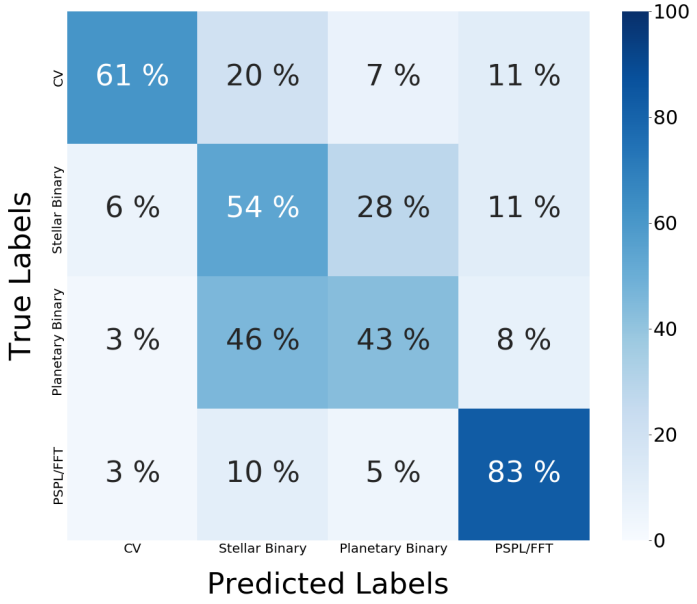
Features

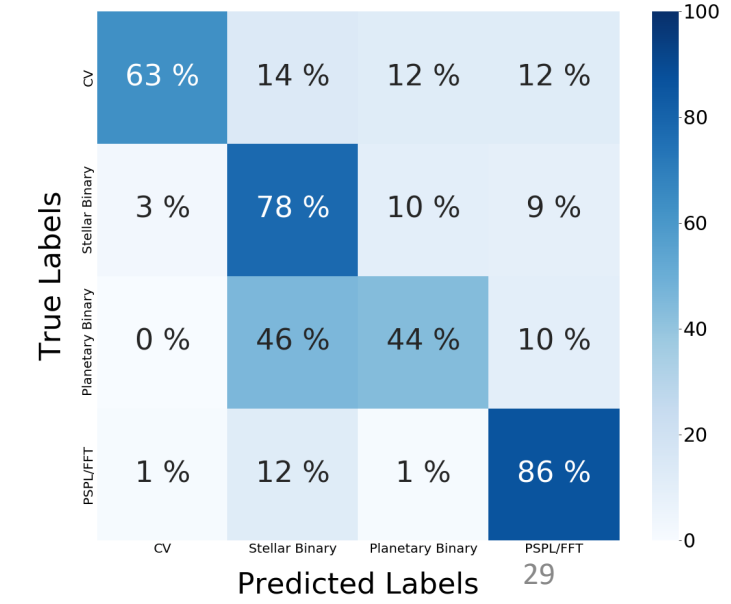
Number of peaks (binsize = 60 days, threshold = 4, 6),
$\Lambda, a_2, a_4, a_6, \beta, \chi^2_{PSPL}, t_{E,PSPL}$











Work under progress

- An ideal dataset would include a variety of stellar variability. We are simulating light curves of variable stars that are likely to be found in Roman's footprint to complete the dataset.
- Testing more complicated Machine Learning Structures and different inputs to them.
- Enhancing the feature definition for lower cadence light curves

Thank You!