Sagan Summer Workshop 2026

# Introduction to Hands-on Sessions

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# Schedule

- Tuesday:
  Hands-On Session I: Microlensing Fits of Single and Binary Lenses
  led by: Casey Lam (Carnegie Obs.), Katarzyna Kruszyńska (LCO), Arjun Murlidhar (OSU), Himanshu Verma (LSU)

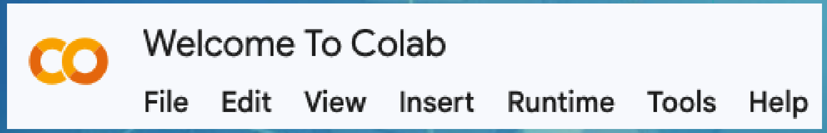
- Wednesday:
  Hands-On Session II: Placing Transit or Microlensing Events in a Galactic Context
  led by: Macy Huston (UC Berkeley), Jessica Lu (UC Berkeley), Matthew Penny (LSU)

- Thursday: Group Projects
  - Each hands-on session offers a few group project options
  - Choose one to work on collaboratively
  - Group sign-up sheet available

- Friday: Group Project Presentations
  - Informal presentations: 5–10 minutes per group

# Getting Started

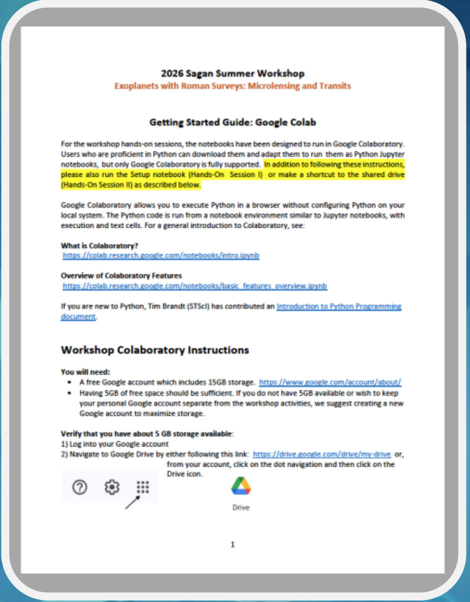
- Open to everyone – all skill levels welcome!
  - We encourage everyone to participate in all the hands-on sessions and in the group projects!
  - Remote attendees can choose to do the hand-on activities live or on their own time
  - Use the #hands-on-session-i, #hands-on-session-ii, #group-projects channels on Slack to ask questions
- Activities will use Google Colaboratory (Colab) notebooks




  - Runs in your browser using Google Drive
  - Requires a Google account with at least ~5 GB of free space
  - If needed, create a new free account (comes with 15 GB of storage)
- Experienced Python users can also download the notebooks and run them locally as Jupyter notebooks
- Visit the SSW website for detailed instructions

# Hands-On Sessions Program

- Copy Google Colab notebooks to your own Google Drive, then run them
  - Instructions provided in PDF document posted on hands-on sessions website: SSW2026_Google_Colab_Instructions.pdf
- Learn the basics in guided tutorials on Tuesday and Wednesday afternoon
- Remote attendees can choose to do the hands-on session activities live or on their own time
- Work on a group project on Thursday afternoon
  - Google sheets will be made available to sign up for group projects
  - Attendees receiving travel support are required to participate in the group projects and presentations
  - Hands-on session helpers (recruited among attendees) and hands-on session leaders are available to help and answer questions (orange lanyards)
  - You can work on the group projects in Baxter Lecture Hall or the Multipurpose Room in the Hameetman Center (closes at 5 pm)
- Short, informal group projects presentations on Friday afternoon
  - Even if you do not have results, just show a progress report



2026 Sagan Summer Workshop
Exoplanets with Roman Surveys: Microlensing and Transits

Getting Started Guide: Google Colab

For the workshop hands-on sessions, the notebooks have been designed to run in Google Colaboratory. Users who are proficient in Python can download them and adapt them to run them as Python Jupyter notebooks, but only Google Colaboratory is fully supported. In addition to following these instructions, please also run the Setup notebook (Hands-On Session I) or make a shortcut to the shared drive (Hands-On Session II) as described below.

Google Colaboratory allows you to execute Python in a browser without configuring Python on your local system. The Python code is run from a notebook environment similar to Jupyter notebooks, with execution and text cells. For a general introduction to Colaboratory, see:

**What is Colaboratory?**
https://colab.research.google.com/notebooks/intro.ipynb

**Overview of Colaboratory Features**
https://colab.research.google.com/notebooks/basic_features_overview.ipynb

If you are new to Python, Tim Brandt (STScI) has contributed an Introduction to Python Programming document.

Workshop Colaboratory Instructions

**You will need:**
- A free Google account which includes 15GB storage. https://www.google.com/account/about/
- Having 5GB of free space should be sufficient. If you do not have 5GB available or wish to keep your personal Google account separate from the workshop activities, we suggest creating a new Google account to maximize storage.

**Verify that you have about 5 GB storage available**:
1) Log into your Google account
2) Navigate to Google Drive by either following this link: https://drive.google.com/drive/my-drive or, from your account, click on the dot navigation and then click on the Drive icon.

Drive

1

# Introduction to Hands-On Session I

Katarzyna Kruszynska, Casey Lam, Arjun Murlidhar, Himanshu Verma

# Microlensing: gravitational lensing, images unresolved → observe transient brightening

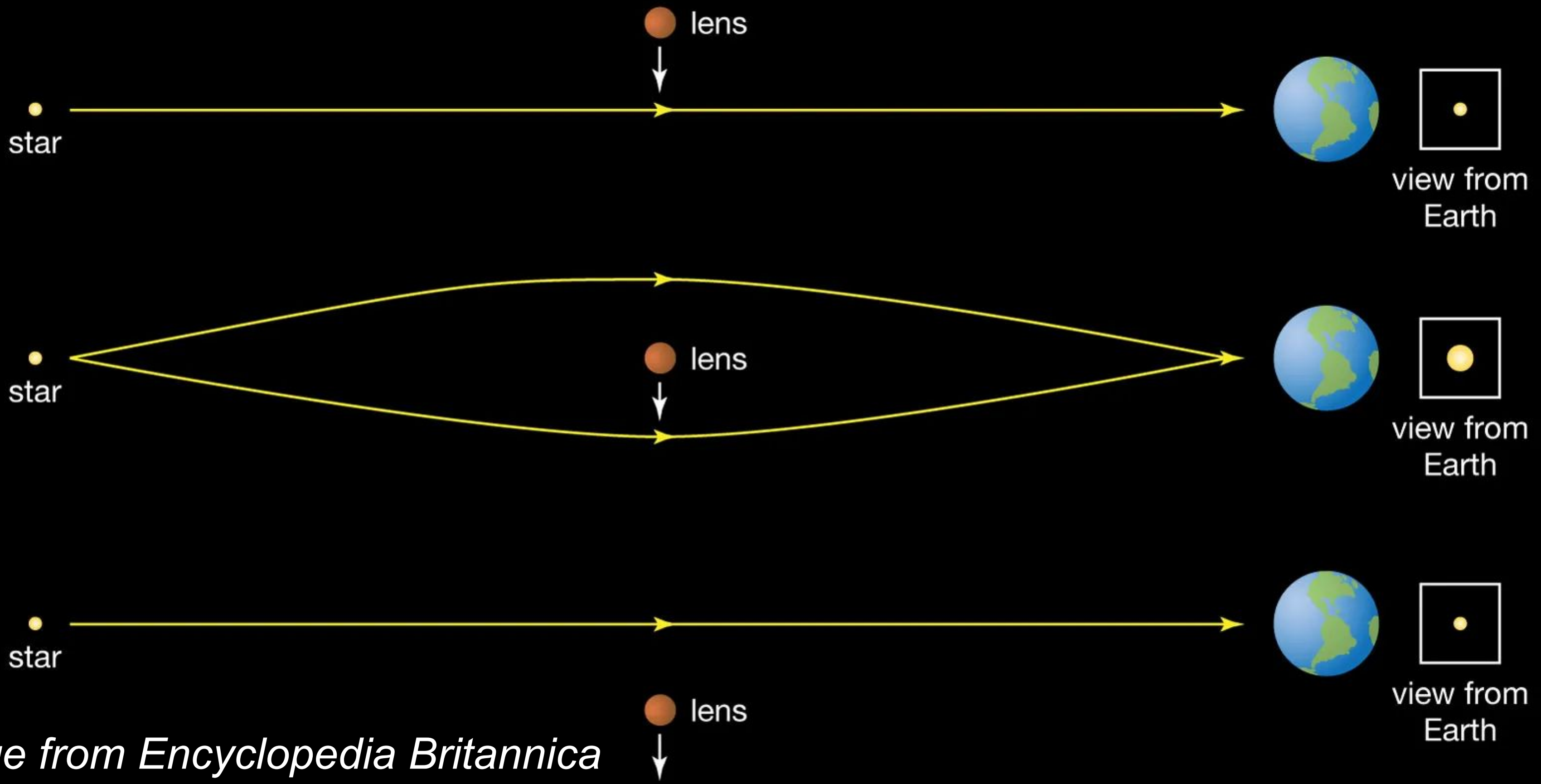
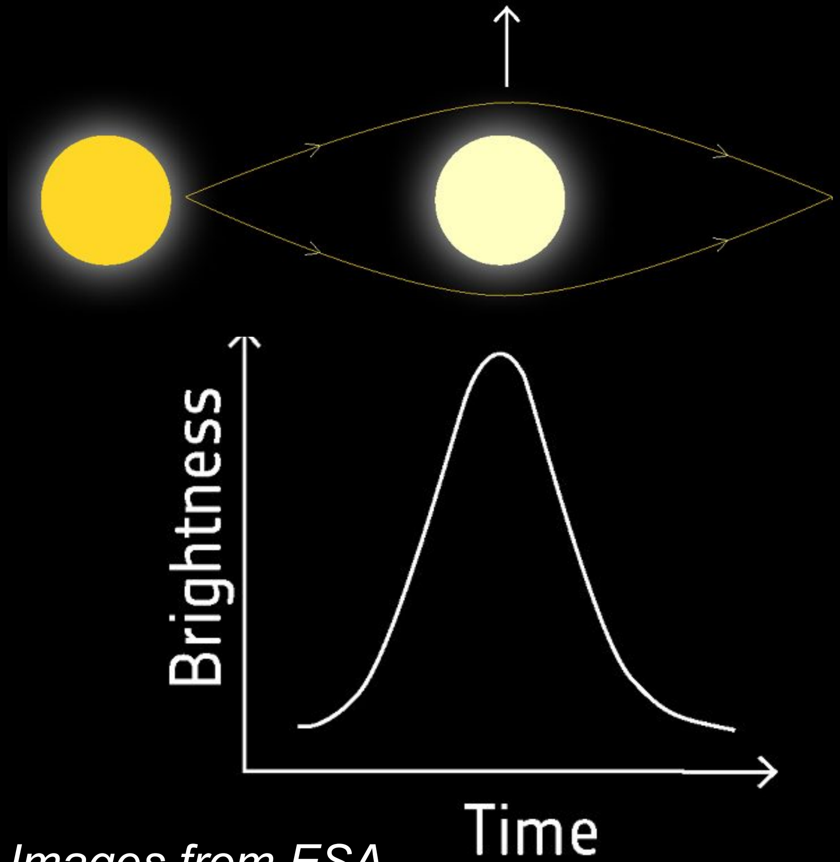



*Image from Encyclopedia Britannica*

# Microlensing can be used to find and characterize planets




*Images from ESA*

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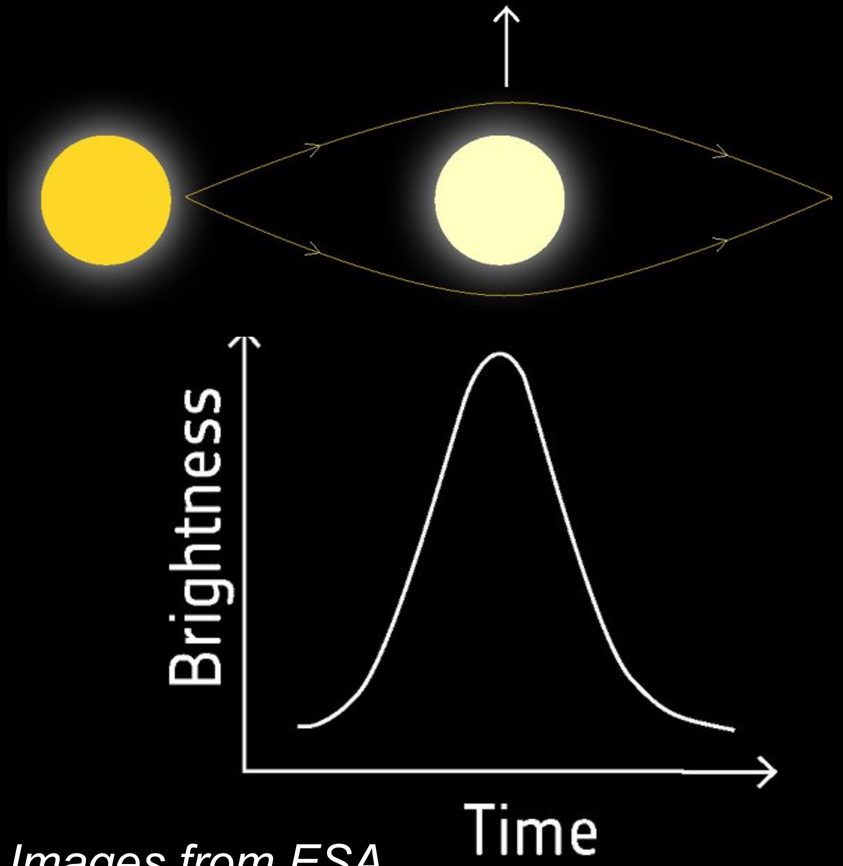
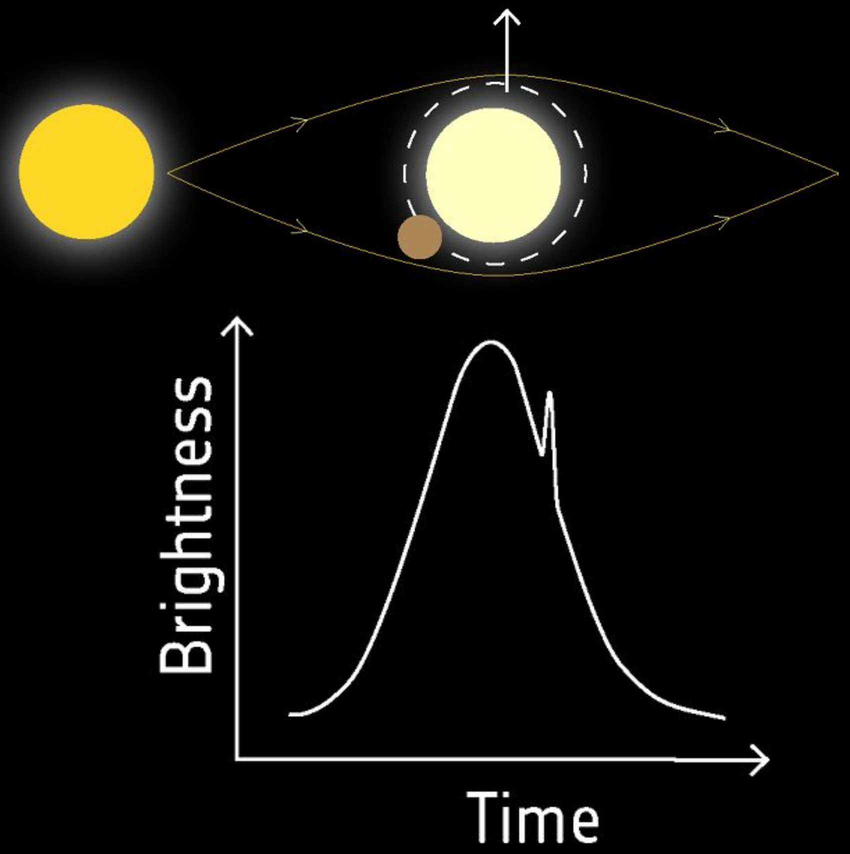
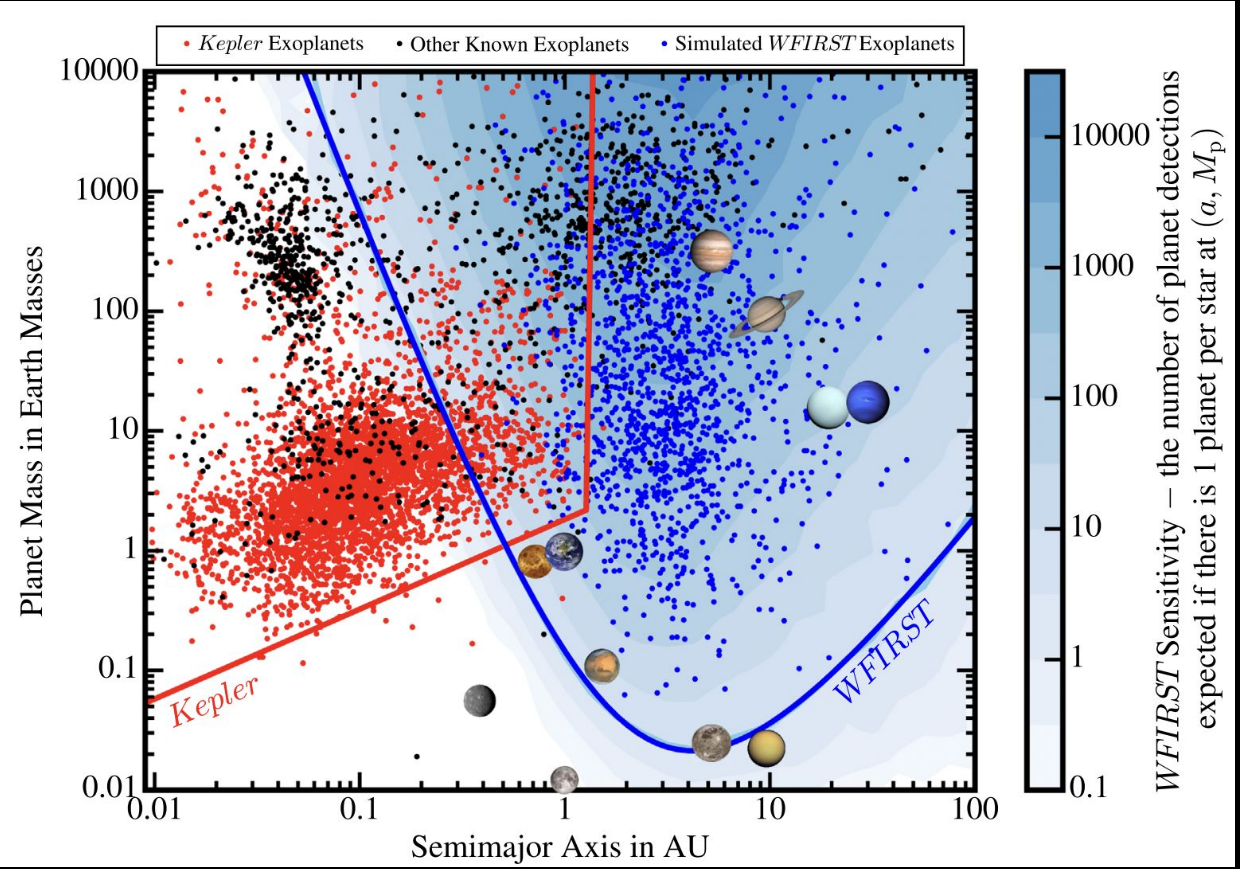



*Images from ESA*

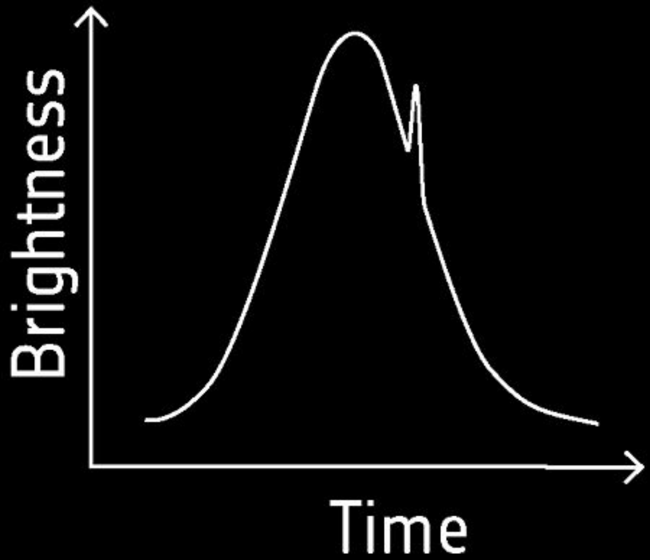
# Microlensing is sensitive to free-floating, <1 $M_\oplus$ planets in ~AU orbits, unreachable by transits, RV, direct imaging, astrometry

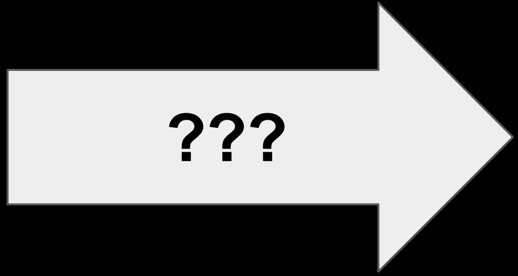



*Penny et al. 2019*

**WFIRST = Roman!*

# How do you get information about a planet and its host star from a microlensing light curve?




*Images from ESA, NASA*

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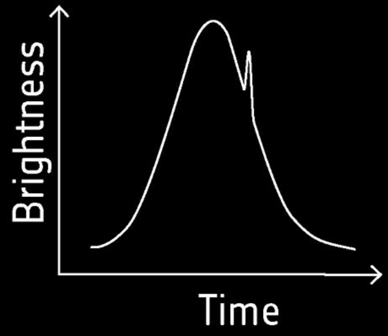
**Microlensing lightcurve**




**Host star and planet properties (distance, mass, temperature)**

# How do you get information about a planet and its host star from a microlensing light curve?

**Microlensing lightcurve**


**Perform model fitting to measure microlensing parameters:**
Geometric single: $t_0$, $u_0$, $t_E$
Geometric binary: $q$, $s$, $\alpha$
Photometric: $f_S$, $m_{base}$
Higher-order effects: $(\pi_{E,E}, \pi_{E,N})$, $\rho$

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**Mass-distance relationship:**
If only 0 or 1 higher-order effects measured, need a Galactic prior

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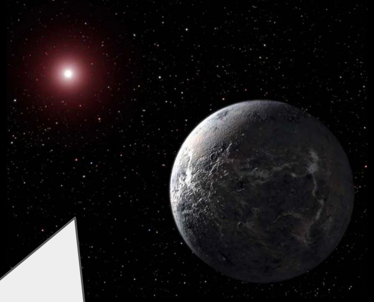

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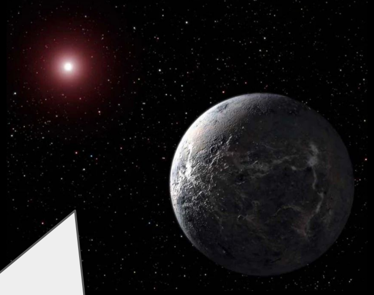


# Hands-on Session I and group project overview

Goals for the session

- How to model single lens + single source models
  - Awareness of higher-order effects like parallax and finite source effects modify lightcurves
- How to model binary lens + single source models
  - How different binary lens parameters and source trajectories affect magnification patterns
  - Understanding how to infer planetary parameters from a lightcurve
  - Awareness of the computational considerations in modeling binary lens microlensing events

# We will use the MulensModel software package to generate microlensing lightcurve models

Code: https://github.com/rpoleski/MulensModel

Documentation (with links to lots of examples): https://rpoleski.github.io/MulensModel/

MulensModel supports these options:

- **Lens Systems:** point or binary lens *(triple lens work in progress)*
- **Source Stars:** single, binary, or even more sources
- **Higher-order effects:** finite source (1-parameter), parallax (satellite & annual), binary lens orbital motion (2-parameter or Keplerian), xallarap effect (with one or two luminous sources)
- **Magnification calculation:** variety of methods and approximations

# We will use the emcee software package to fit microlensing models to simulated Roman lightcurves

Code: https://github.com/dfm/emcee

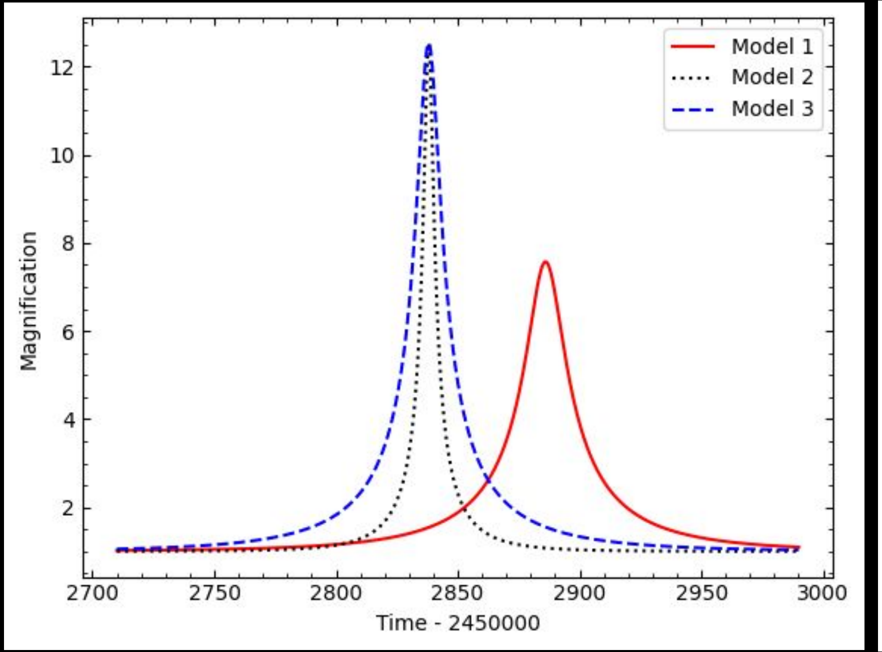
Documentation: https://emcee.readthedocs.io

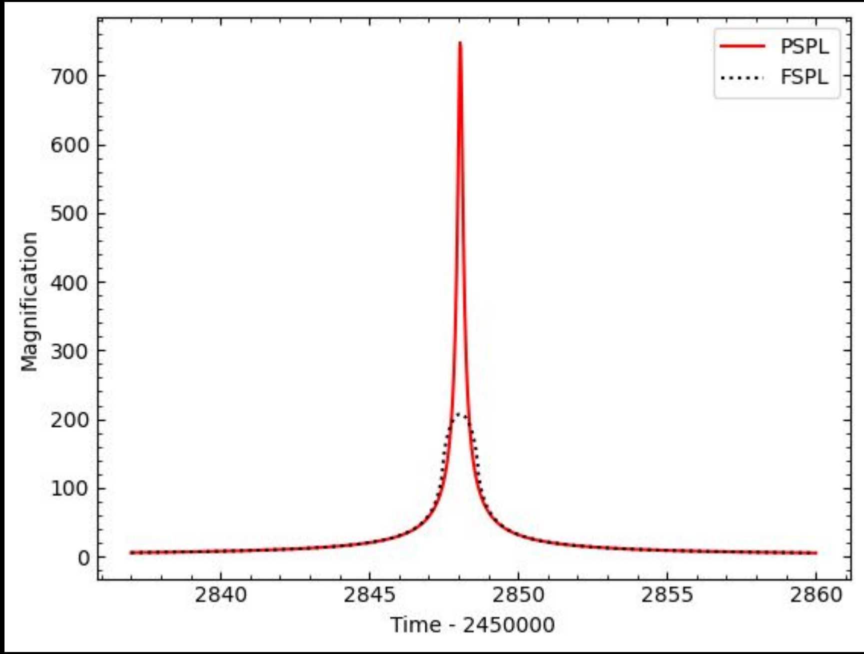
emcee is a python implementation of a particular Markov chain Monte Carlo (MCMC) algorithm (Affine Invariant Ensemble sampler)

- Generically, MCMC is used to draw samples from a probability distribution
- MCMC is useful for comparing models to data (aka fitting) to perform parameter inference (with uncertainties)
- emcee is **not** microlensing specific (in fact, you may have used it before to fit some other kind of dataset!)

# Part 1: Single Lenses

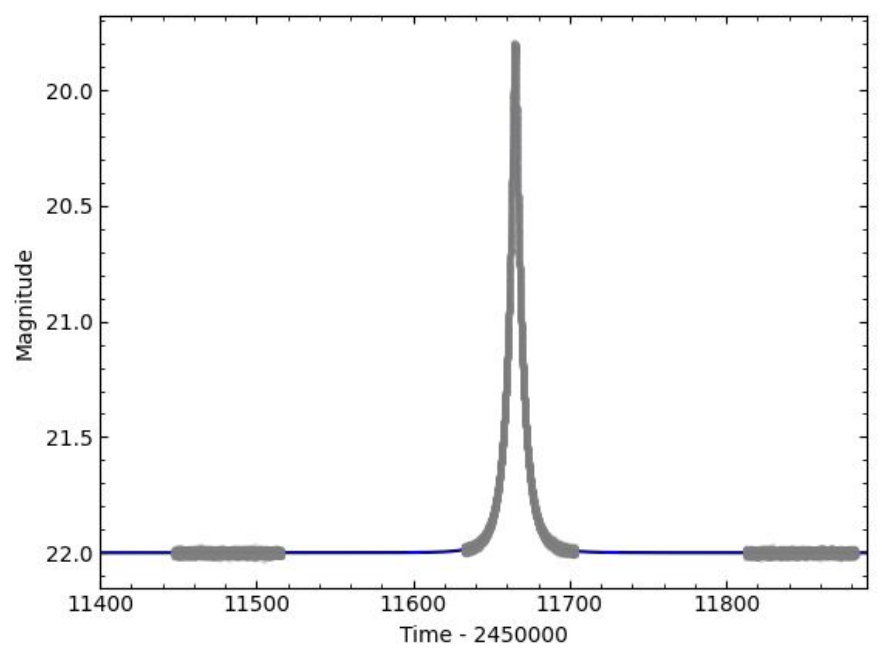
a) Create single lens lightcurves with MulensModel; explore the impact of higher-order effects (finite sources, parallax)

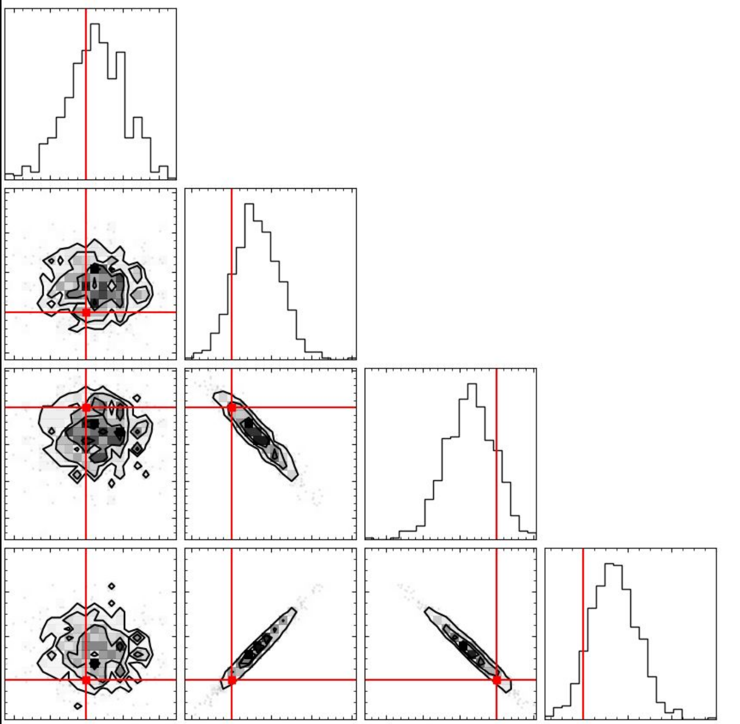


# Part 1: Single Lenses

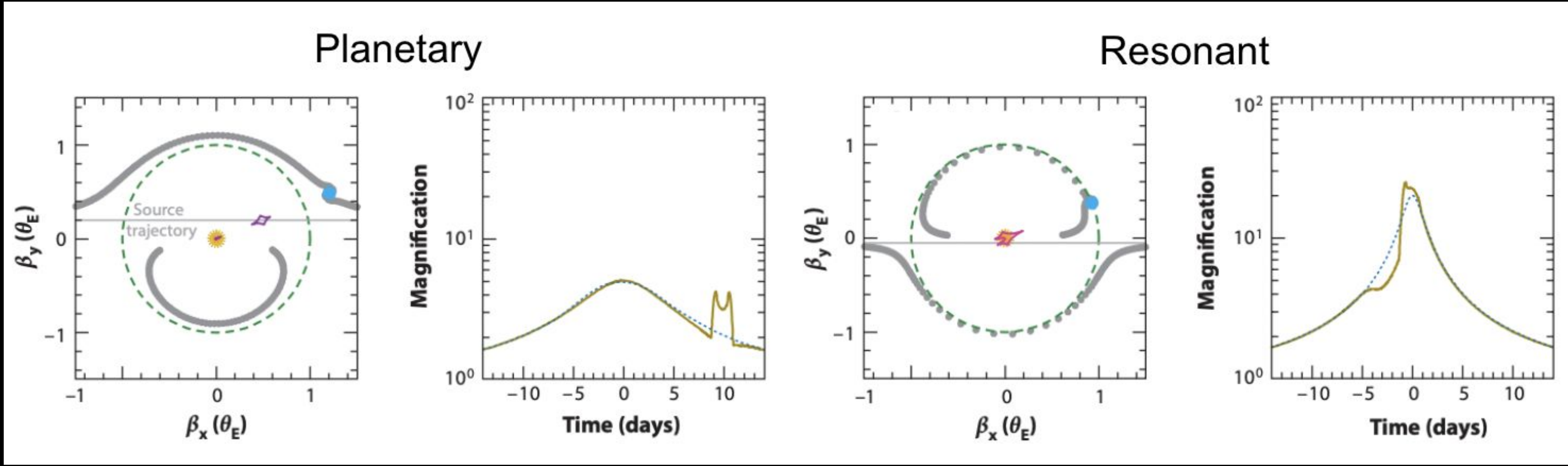
b) Fitting point-source point-lens (PSPL) model to synthetic Roman data using MCMC to infer microlensing parameters



# Part 2: Binary/planetary lenses

a) Explore binary lens parameter space; build some intuition for the combinations of parameters that lead to different classes of lightcurves ("topologies")




*Gaudi 2012 review*

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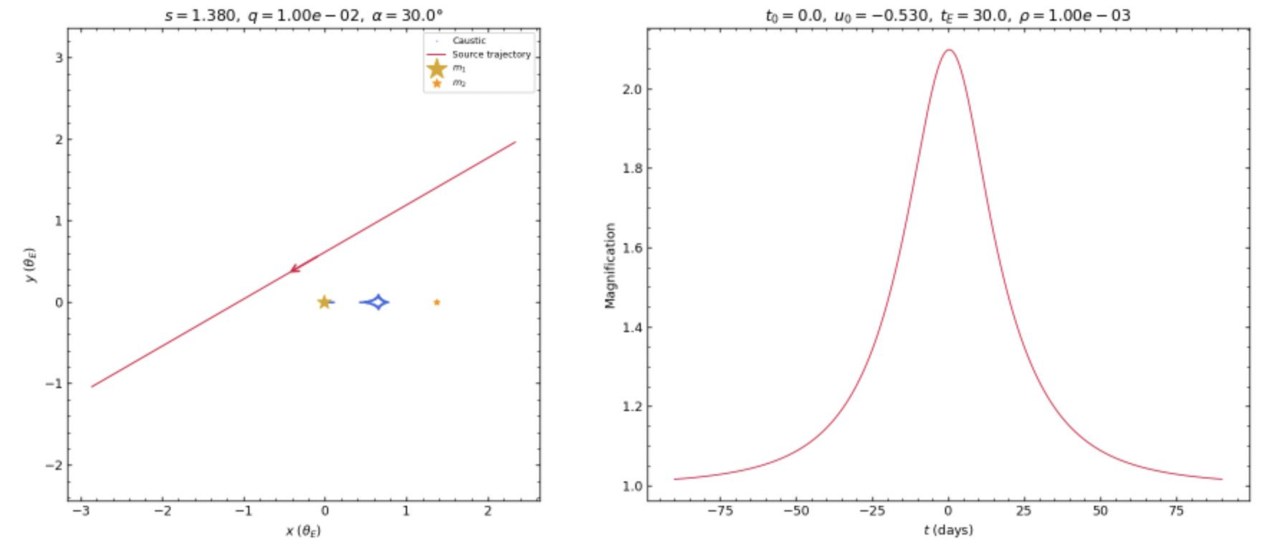
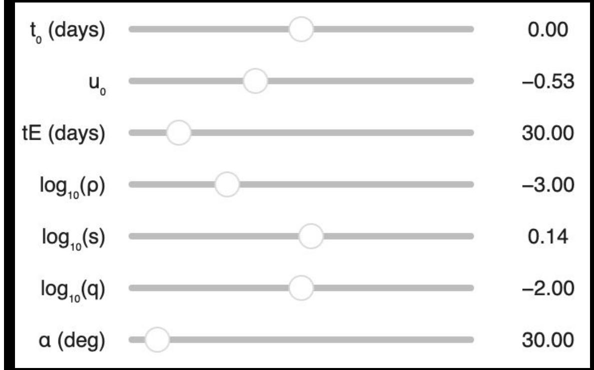
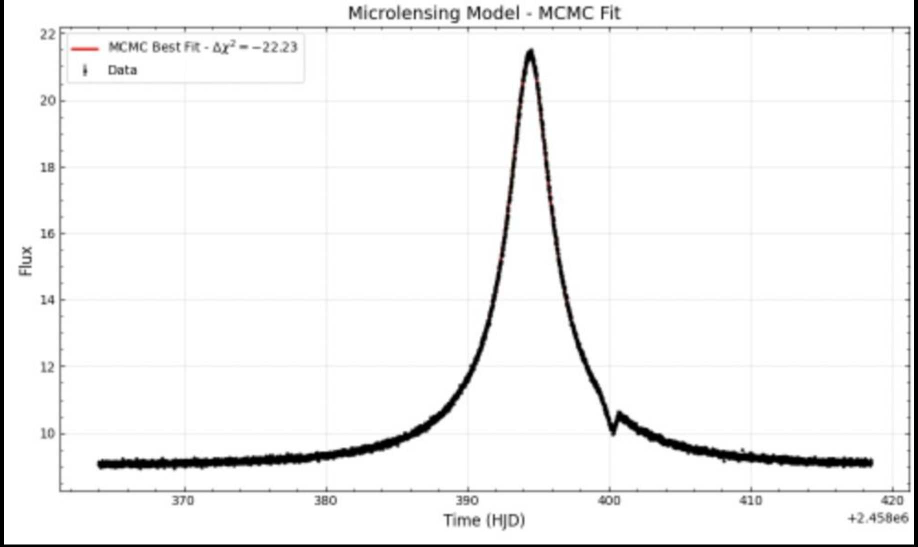
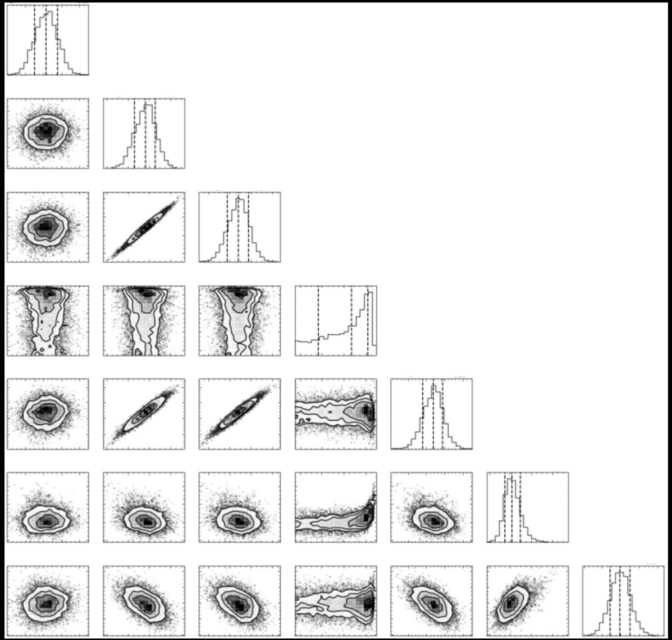


# Part 2: Binary/planetary lenses

b) Fitting binary lens models to synthetic Roman data using a grid search* + MCMC to infer microlensing parameters (*computationally expensive, so we will provide pre-computed intermediate results)



# Hands-on Session I group projects

More practice fitting lightcurves with MulensModel and emcee (reviewing, applying, and reinforcing what we go over in the Hands-on Session)

You will be provided with a large set of of single lens and binary lens lightcurves

- You are **not** expected to fit all of them! (Just do one, maybe a few)
- Single lens: recommended if you are new to microlensing
- Binary lens: recommended if you have microlensing experience

# Other comments

In addition to MulensModel, a compilation of other microlensing modeling codes can be found at https://www.microlensing-source.org/software/

MCMC is not the only algorithm that can be used for model fitting (e.g., nested sampling), and even for just MCMC there are a variety of algorithms (e.g., no U-turn sampling, simulated annealing, …)

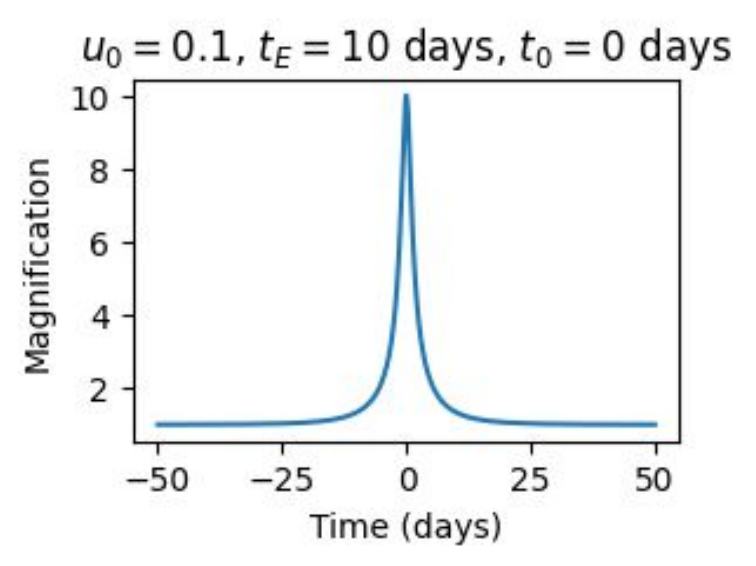
# You can make a microlensing lightcurve with 2 lines of code!

```python
def A(u):
    """
    The magnification equation as a function of the
    dimensionless source-lens projected separation u.
    """
    A = (u**2 + 2)/(u * np.sqrt(u**2 + 4))
    return A
```

```python
def u(t, tE, u0, t0):
    """
    The dimensionless source-lens projected separation u
    as a function of time.

    t : time.
    tE : Einstein crossing time.
    u0 : impact parameter.
    t0 : time of closest approach.
    """
    u = np.sqrt(u0**2 + ((t - t0)/tE)**2)
    return u
```

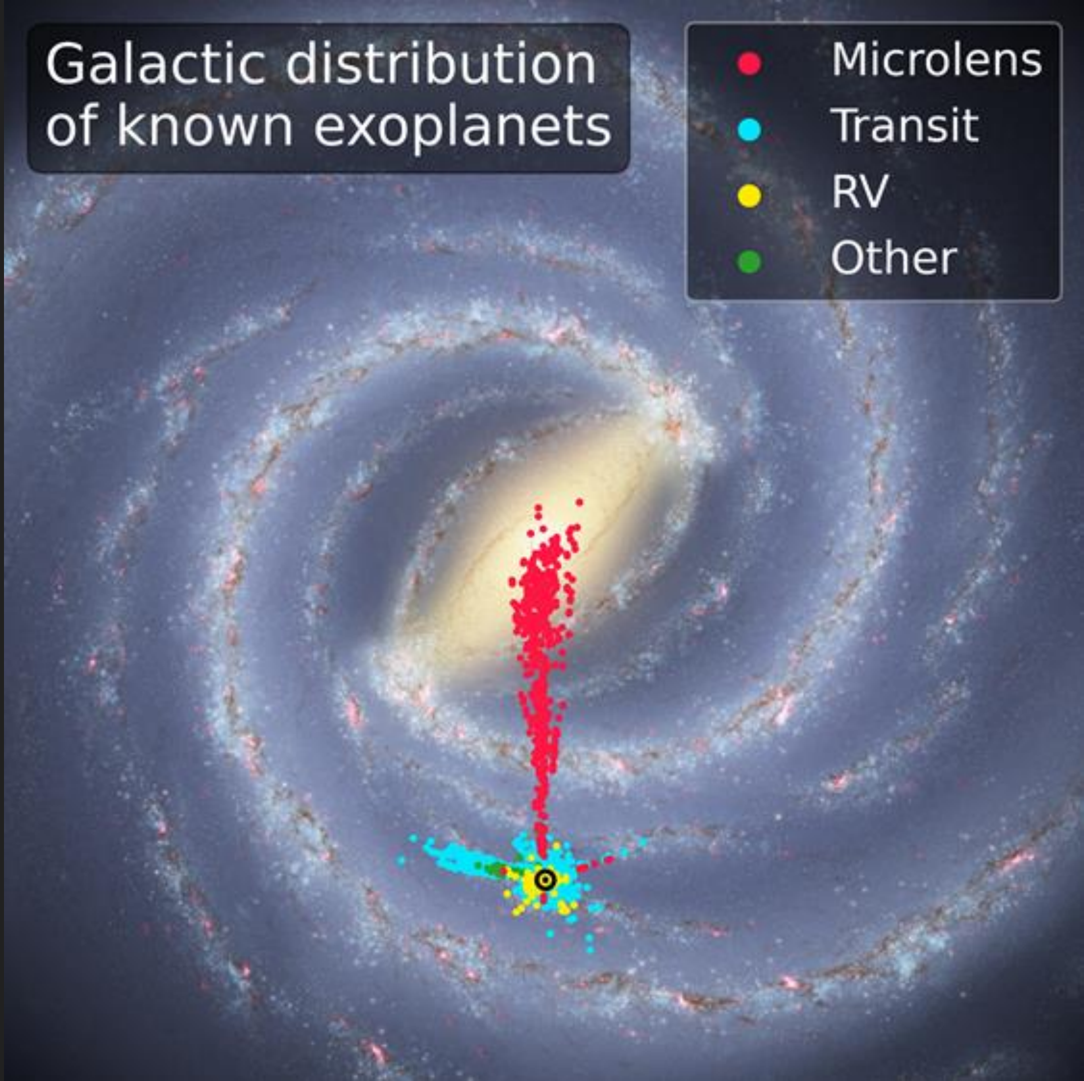
```python
t = np.linspace(-50, 50, 1000)
plt.plot(t, A(u(t, 10, 0.1, 0)))
plt.xlabel('Time (days)')
plt.ylabel('Magnification')
plt.title('$u_0=0.1$, $t_E=10$ day, $t_0=0$ day')
```



# Hands-on Session II: Placing an Exoplanet Host Star in its Galactic Context

Macy Huston & Jessica Lu

Microlensing probes parts of the Galaxy we can’t typically reach with other methods.




NASA Exoplanet Archive data, July 2026

MW Image: NASA/R. Hurt

# Microlensing Provides Limited Information

From a microlensing light curve alone, we get:

- Timescale ($t_E \propto M_L^{1\backslash 2}\ \pi_{rel}^{1/2}\ \mu_{rel}^{-1}$)
    - degenerate function of lens mass, distances, and proper motions
- Mass ratio q
- Projected separation s

We'll need second-order effects and/or additional follow-up to:

- Measure the true mass of the planet and its host star
- Estimate the source star's age and metallicity
- Understand the planet's context within the broader picture of planet formation

# Mock Roman Data Sets

Star catalog:

- Magnitudes in all filters if detectable for all “stars”
    - Note: “stars” may be multiple blended objects
- Proper motions & parallaxes

Event catalog:

- Microlensing events with microlensing parameters (timescale, etc.)
- For detectable lenses, we assume measured lens-source separation
- For non-detectable lenses, you can explore a more limited set of information

Light curves (for optional group project use):

- Microlensing light curve for each event in the main events catalog

# Mock Roman Data Sets

Simulation catalog:

- Detailed information about all stars' underlying properties
- No magnitude limit
- Un-blended

Isochrones:

- Expected magnitudes for stars of a single-age, single-metallicity population and a given extinction

# Hands-on Session Tasks

Examine an example microlensing event in context with the rest of the observed stars and against simulated stars:

- Color-magnitude diagrams
- Spectral energy distribution
- Parallax & proper motion
- Takeaways about your planet and its host star

# Group Projects

1. Examine a microlensing event toward the Galactic Center.
2. Examine a microlensing event with a dark lens.
3. Write a simple SED fitter to characterize a single star in more detail.
4. Examine microlensing light curves to find a binary event and see how this analysis differs.