KSP 5.0

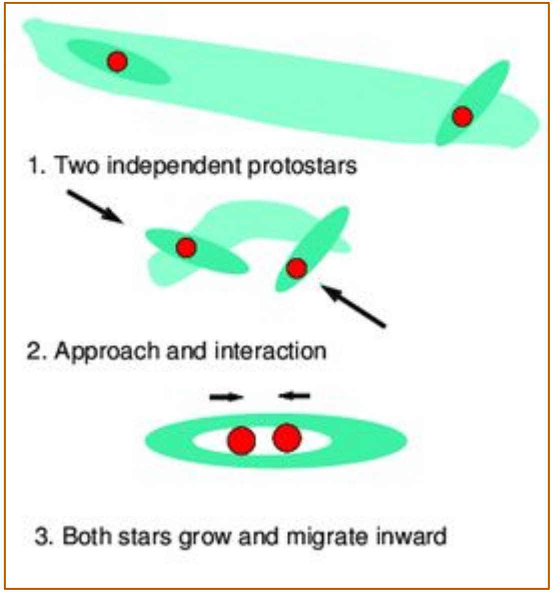
Eclipsing Binaries Project

Binary Star Systems

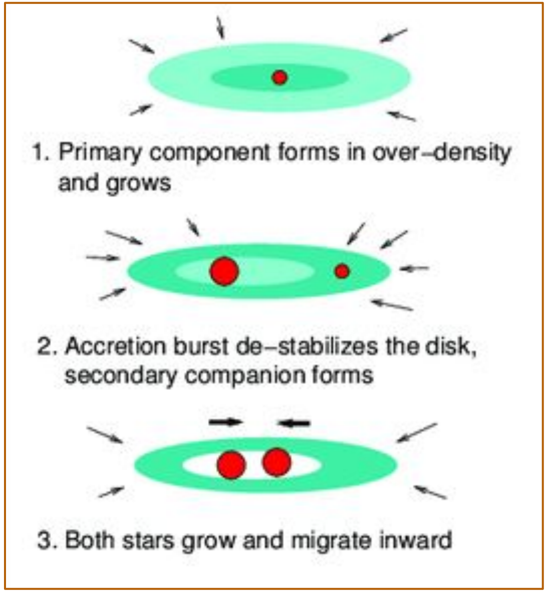
Types of Binary Stars

1. **Visual binaries**: Seen directly through telescopes.
2. **Spectroscopic binaries**: Identified by periodic shifts in their spectral lines due to their orbital motion.
3. **Eclipsing binaries**: Detected by changes in luminosity as one star passes in front of the other.
4. **Astrometric binaries**: Detected by observing the wobble in a star's position due to an unseen companion.

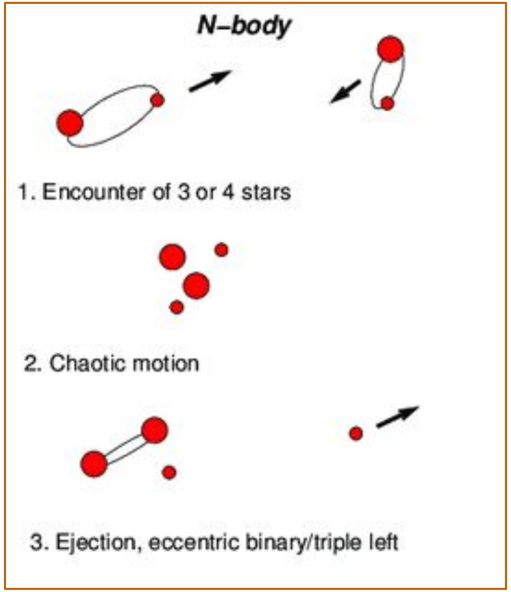
Origins and Formation



Turbulent Fragmentation



Disk Fragmentation



Dynamical Formation

Orbital Mechanics Overview

$$r = \frac{l}{1 + e\cos\theta}$$

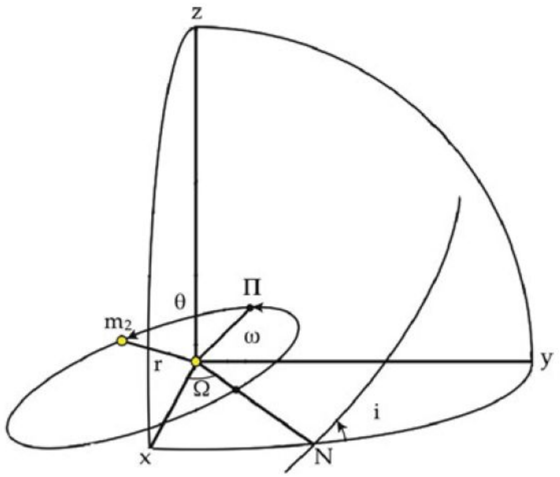
The Orbit Equation for the reduced body

$$x^2(1 - e^2) + 2exl + y^2 = l^2$$

The general equation for the orbit

Orbit Type	**Eccentricity (e)**	**Total Energy (C)**	**Equation**
Circular	$e = 0$	$C = C_{min} = -\frac{Gm_1m_2}{2l} < 0$	$x^2 + y^2 = l^2 = r_0^2$
Elliptical	$0 < e < 1$	$C_{min} < C < 0$	$y^2 + Ax^2 - Bx = k$
Parabolic	$e = 1$	$C = 0$	$x = \frac{y^2}{2r_0} - \frac{r_0}{2}$
Hyperbolic	$e > 1$	$C > 0$	$y^2 - Ax^2 - Bx = k$

Elliptical Orbits and Orbital Elements



- Angle of Inclination, i
- Longitude of the ascending node, Ω
- Longitude of the periastron, ω
- Semimajor Axis, a
- Eccentricity, e
- Time of Periastron, T

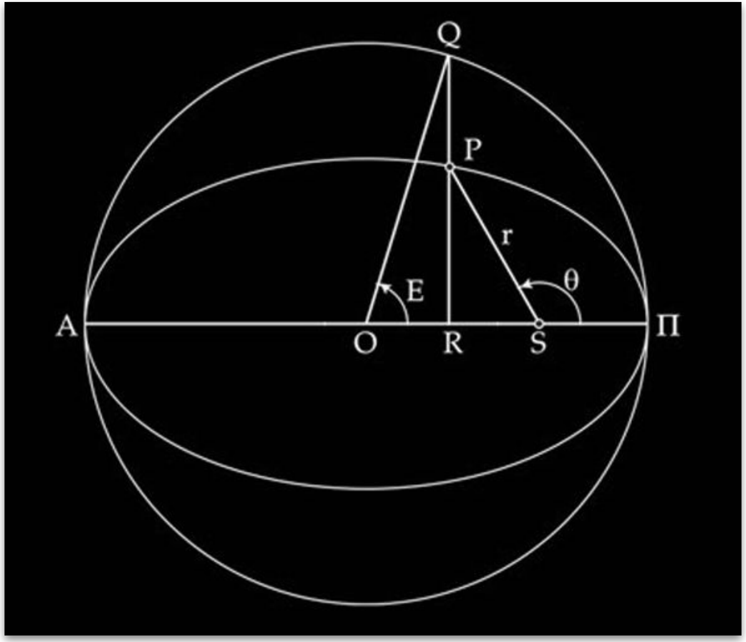
Time Dependence

$$E - e\sin E = \frac{2\pi}{P}(t - T) \quad \text{or} \quad E - e\sin E = \frac{L}{ab}(t - T)$$

where:

$$r = a(1 - e\cos E)$$

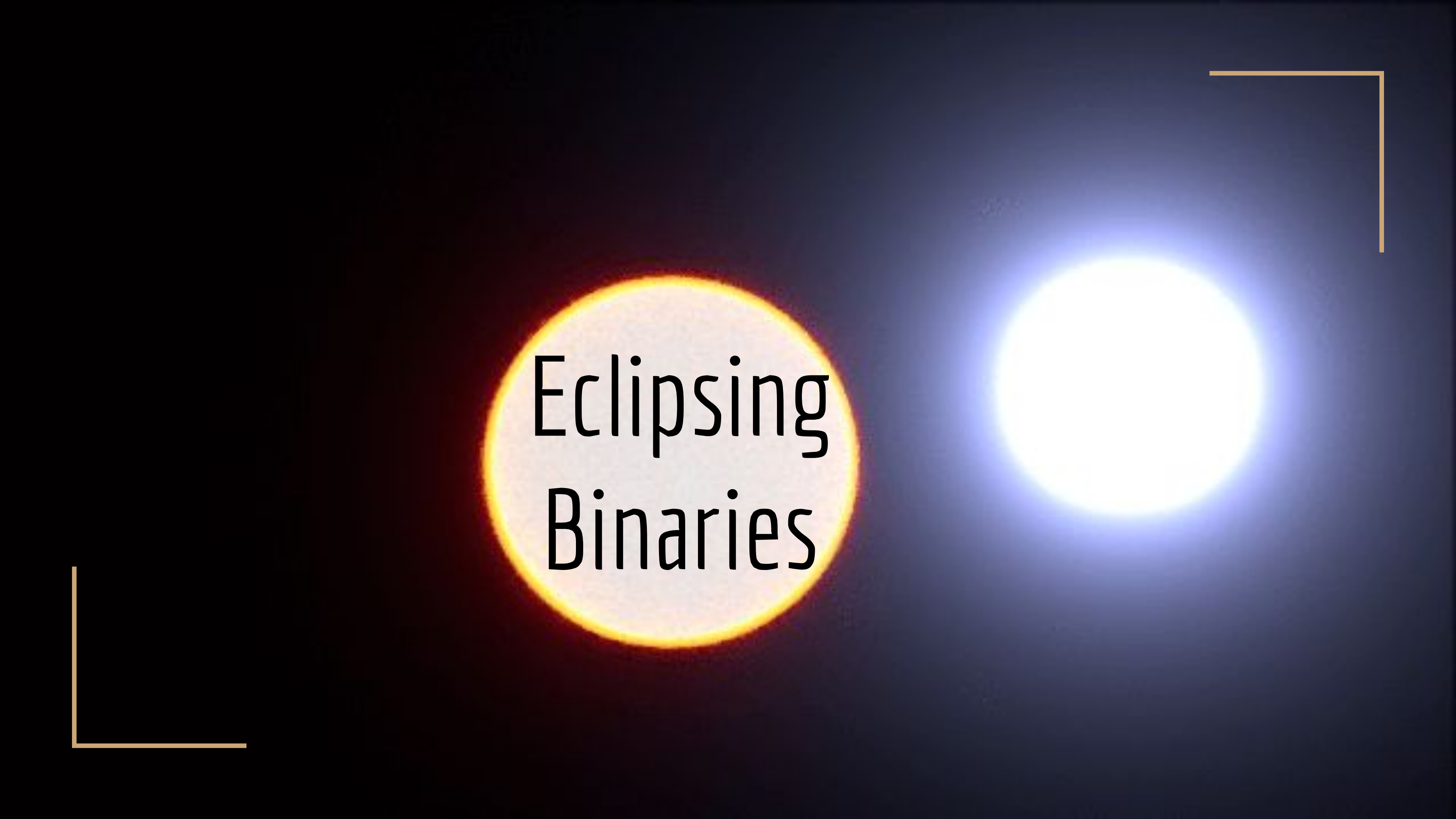
$$\sin\theta = \frac{\sqrt{1 - e^2}}{1 - e\cos E}\sin E$$



Workflow and Objectives

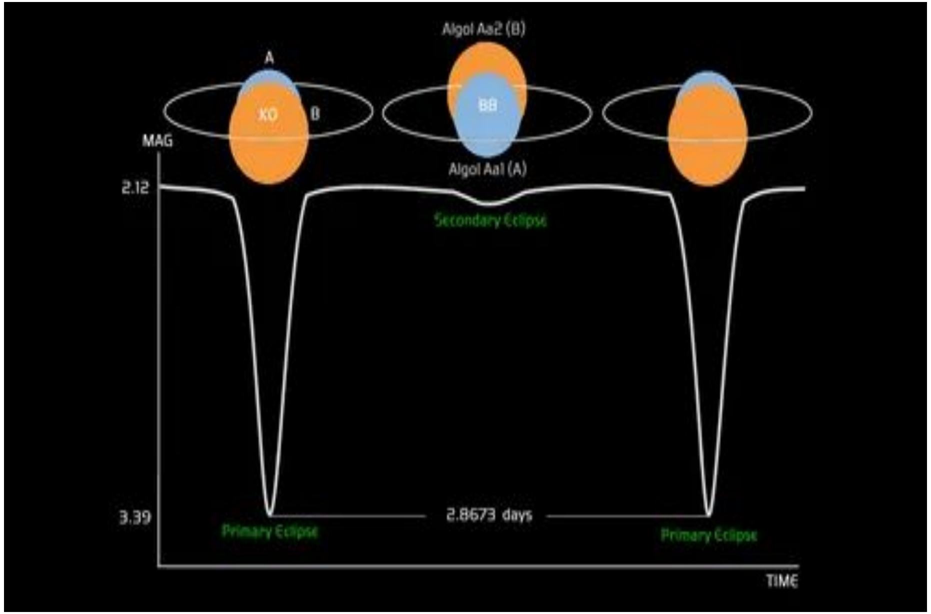
Our workflow involves several key steps:

1. **Data Collection**: Gathering observational data on eclipsing binaries.
2. **Modeling**: Using PHOEBE to create detailed models of the binary systems.
3. **Parameter Estimation**: Deriving physical parameters from the models.
4. **Analysis**: Interpreting the results to enhance our understanding of these systems.


Eclipsing
Binaries

What are Eclipsing Binaries?

- Binaries in which the orbital plane of the two stars lies so nearly in the line of sight of the observer that the components undergo mutual eclipses are called Eclipsing Binaries.
- They are characterized by periods of constant light, punctuated by periodic drops in intensity when one star passes in front of the other.



Why are Eclipsing Binaries Important?

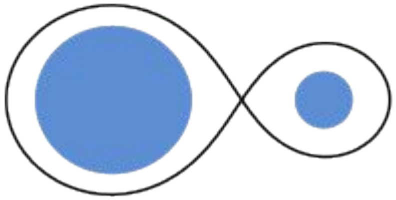
Eclipsing binaries are important astrophysical objects as they allow astronomers to determine the masses, radii, and other physical properties of the component stars through careful analysis of the light curves and other observational data.

	Astrometric Binaries			Spectroscopic Binaries		Eclipsing Binaries		
	alone	with distance	with RVs	SB1	SB2	alone	SB1	SB2
No. of Retrievable Parameters	7	10	20	7	13	5	10	27

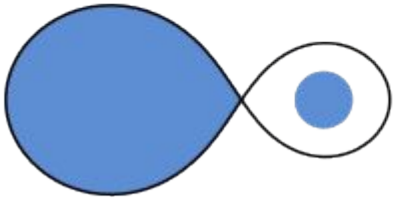
Types of Eclipsing Binaries

1. **Detached:** Well-separated stars with minimal interaction.
2. **Semi-detached:** One star fills its Roche lobe, transferring mass
3. **Overcontact:** Close binary with tidally distorted stars, potentially sharing a common atmosphere

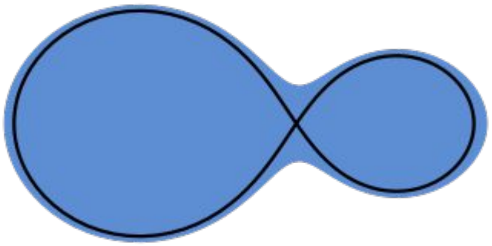
Types of Eclipsing Binary Stars



Detached



Semi-Detached

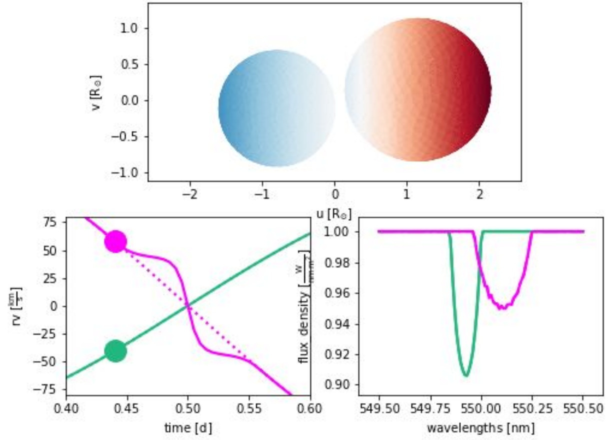


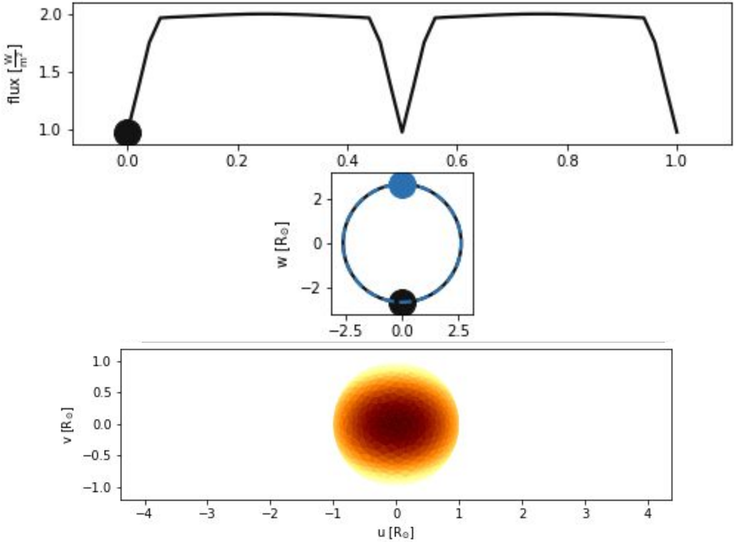
OverContact

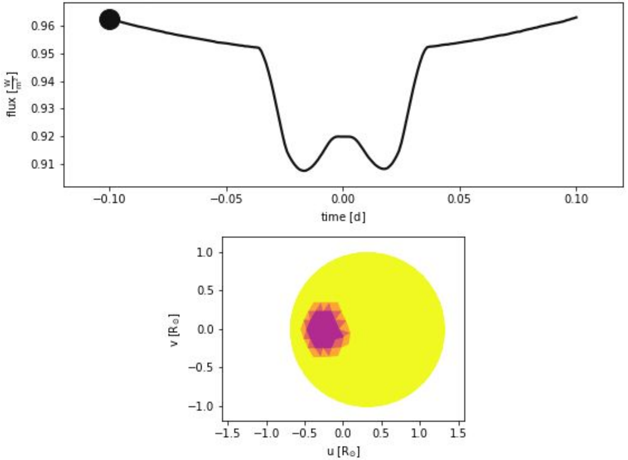
PHOEBE

PHOEBE (PHysics Of Eclipsing BinariEs)

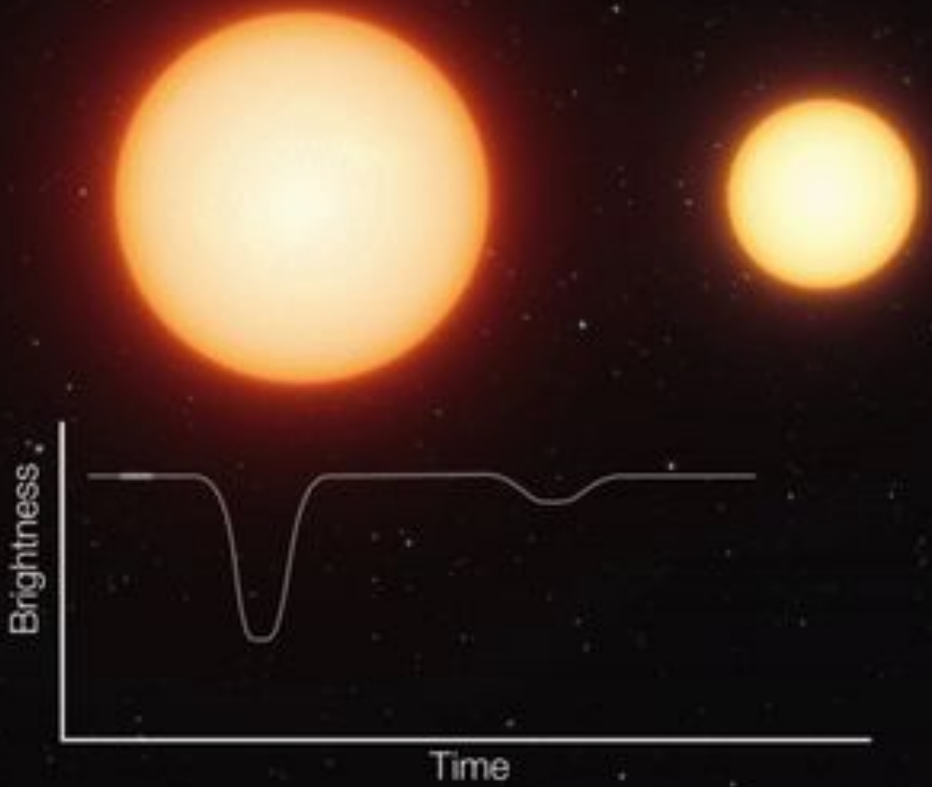
- A powerful and versatile Python package designed specifically for the analysis and modeling of eclipsing binary stars.







FORWARD MODELING



What Is Forward Modeling?

Forward Modeling is essentially the simulation of a real-world process.

Why is PHOEBE used for Forward Modeling of Eclipsing Binaries?

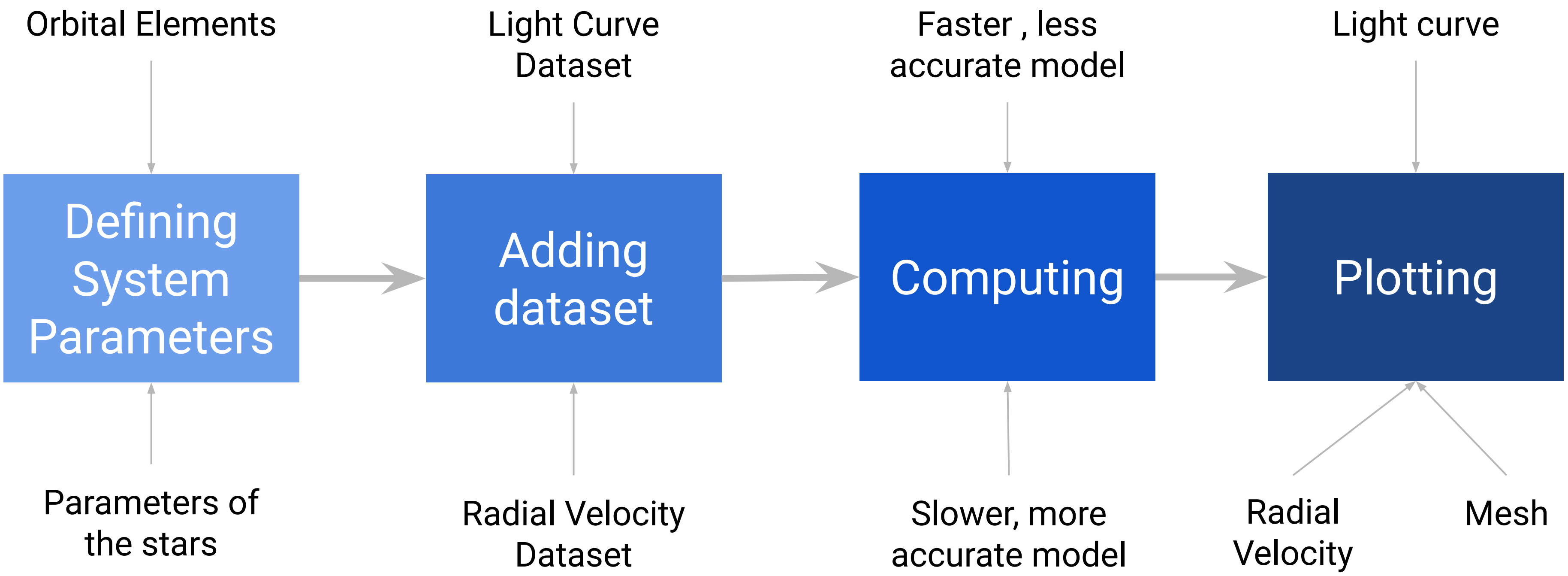
It provides us with a comprehensive toolkit for simulating and interpreting the complex interactions between binary star systems.

Why is Forward Modeling used?

Forward modeling has many application such as

- understanding the relationship between causes and effects.
- Testing theoretical models and improving them.
- Forecasting future events which Sometimes results in unexpected features in the observed light curve, hinting at new physical processes.

Key Steps in Forward Modeling for Eclipsing Binaries



Inverse Problem

What is an Inverse Problem ?

In the context of Eclipsing Binaries, inverse problem involves determining the underlying orbital parameters and stellar parameters based on the observational data, in the form of light and radial velocity curves.

Fitting EBs, is anything but straightforward, and the root cause of that is the **complexity of the parameter space**

Merit Function

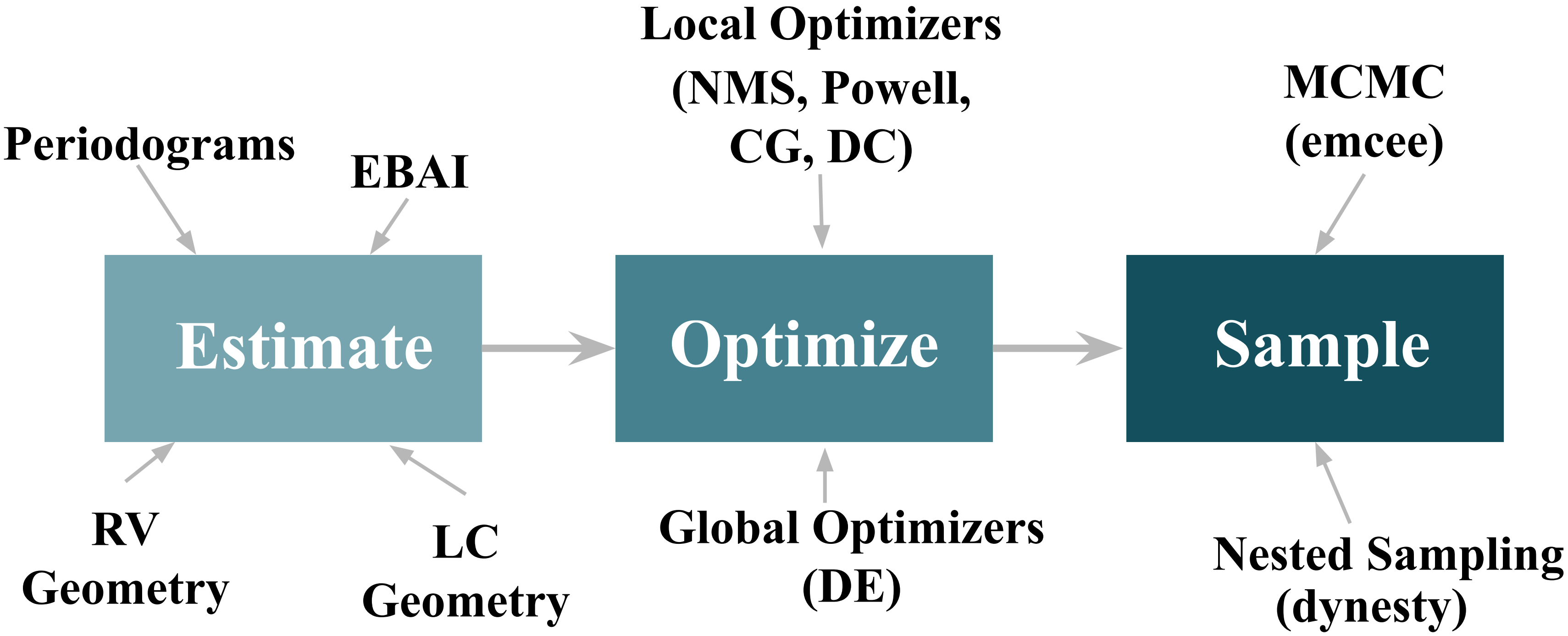
$$chi - squared: \quad \chi^2 = \sum_{datasets} \sum_{k} \left\{ \frac{\left(y_k^{\,o} - y_k^{\,m}\right)^2}{\sigma^2_{\ k}} + \ln\left(2\pi\sigma_k^{\ 2}\right) \right\}$$

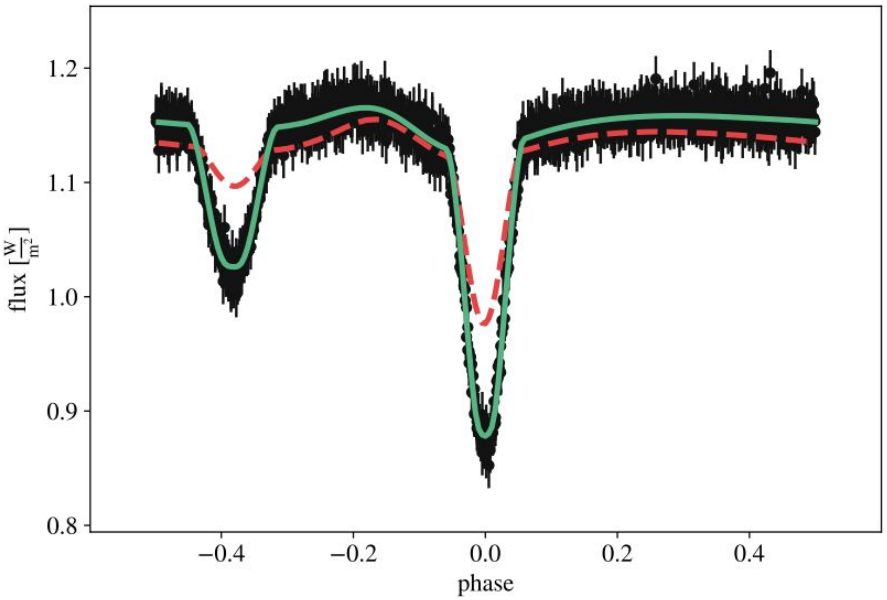
$$MLE: \quad \ln f = -\frac{1}{2}\chi^2$$

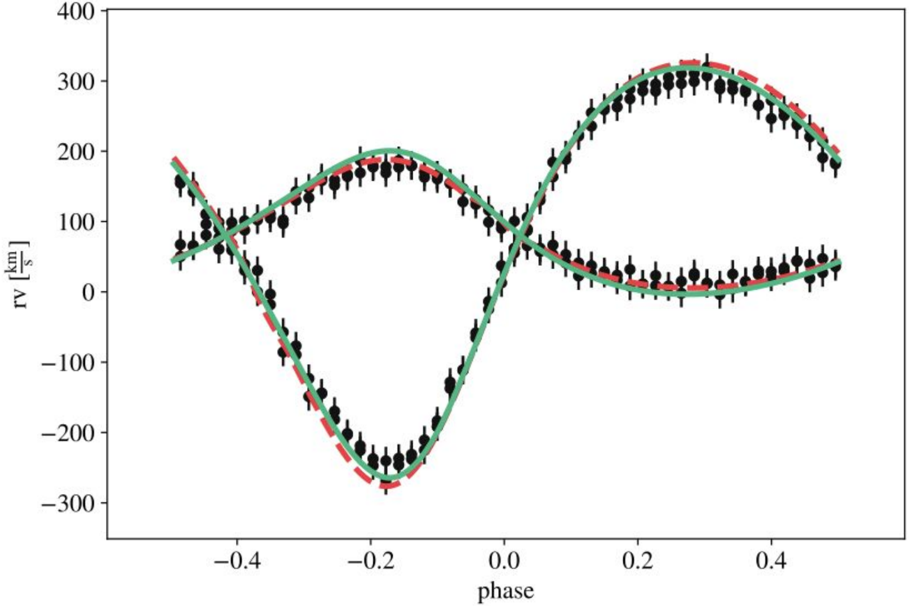
$$\log - priors: \quad \ln\pi = \sum_{priors} \ln\pi(x)$$

$$\log - probability: \quad \ln p = \ln f + \ln\pi$$

Phoetting Recipe







Model improvement after adopting proposals from estimators (dashed red lines) and after running Nelder-Mead (solid green lines)

THANK YOU