Statistical Opportunities in Microlensing

The goal of this talk:
To start a conversation

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Problems and Opportunities:

“Closer” to light curves (i.e. more data-centric)

• Correlated noise in light curves - how does a more advanced noise model change your inferred parameter values?

• Computationally expensive ray-shooting codes - can statistical emulation speed up microlensing parameter estimation?

• Likelihood of data given parameters can be multimodal, and caustic topographies are not continuous - how to choose the best model?

• Population analyses depend on uncertain and correlated parameter values for individual events - how to account for these in a self-consistent probabilistic framework?

“Farther” from light curves (i.e. more model-centric)
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From Michael Albrow’s 2017 talk

From Youn Kil Jung’s 2017 talk

From Daisuke Suzuki’s 2017 talk
Correlated Noise

Lesson learned from transits: Kepler-91 b (Barclay et al. 2015)
Correlated Noise

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Is there a planet at all?!?

(modeled noise with Gaussian Process Regression)
Correlated Noise

Lesson learned from transits: Kepler-91 b (Barclay et al. 2015)

Is there a planet at all?!? (modeled noise with Gaussian Process Regression)

with GPR

without GPR

YES.
Correlated Noise

Lesson learned from transits: Kepler-91 b (Barclay et al. 2015)

1) Correlated noise can be significant for red giants (common microlensing source)

2) Can drastically change your detections & parameter values!

Is there a planet at all?!?! (modeled noise with Gaussian Process Regression)

YES.
Correlated Noise

Lesson learned from radial velocities: RV Fitting Challenge

(Dumusque et al. 2017)

1) A Bayesian framework + red noise model produces more reliable and complete detections.

2) Inflexible noise models more often lead to inaccurate parameter values.
Correlated Noise
Effect on microlensing parameters (from Albrow’s 2017 talk)
Correlated Noise
Effect on microlensing parameters (from Albrow’s 2017 talk)

Red noise can seriously mislead you, too!! Test more than \( t_E \)!
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Is there a more efficient way to compute the grids of $q$, $s$, and $\alpha$?

YES: statistical emulation . . . plus it allows you to interpolate the grid for free . . . plus that interpolation is probabilistic.
Statistical Emulation

A 1-dimensional conceptual example

Use a Gaussian Process to predict the true, unknown function (with uncertainties) between the “observed” points (where the expensive code was run)

Courtesy of Derek Bingham
Statistical Emulation

A multi-dimensional astrophysical example (Czekala et al. 2017)

Simulated the time-varying spectrum of an SB1 binary star system

Used a Gaussian Process emulator to model the spectrum, predict/interpolate the radial velocities of each component, and infer both stars’ masses.
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Model Comparison

Which caustic topology best fits the data?

Actually have 3 separate models to fit to the data …
Which caustic topology best fits the data?

Actually have 3 separate models to fit to the data … which leads to multimodal likelihood spaces.

Is it better to identify a single point as a best fit, or to integrate over the parameters for that model to identify most likely topology?
Model Comparison

Which caustic topology best fits the data?

Actually have 3 separate models to fit to the data …

How can you do model comparison?
See Ben Nelson’s talk on Saturday with lessons learned from RV.

a single point as a best fit, or to integrate over the parameters for that model to identify most likely topology?
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Microlensing Populations

Within a Hierarchical Bayesian Framework

What do I mean?

Individual Parameters
(likelihood $\rightarrow$ MCMC)

Observables
Microlensing Populations

Within a Hierarchical Bayesian Framework

What do I mean?

Population Parameters

Expand your likelihood!

Individual Parameters

Observables

\[ \alpha \]

\[ \theta_i \]

\[ x_i \]

\[ N \]
Microlensing Populations
Within a Hierarchical Bayesian Framework

What do I mean?

Structure helps constrain posteriors:
Wolfgang & Lopez, 2015
Microlensing Populations

Within a Hierarchical Bayesian Framework

What do I mean?

Population Parameters

Individual Parameters

Observables

Why do we need it?

- Parameter inference with uncertainties
- Naturally deals with large measurement uncertainties and upper limits
- Can account for selection effects *within* the inference
- Simultaneous posteriors on individual and population parameters
- Directly ties theory to observations
- Framework for model comparison

Structure helps constrain posteriors: Wolfgang & Lopez, 2015

Still use MCMC: “Just” adding another layer of probabilistic structure

Still use MCMC: “Just” adding another layer of probabilistic structure
Microlensing Populations

What would a hierarchical Bayesian framework add?

1) Uncertainties in population can easily and self-consistently incorporate uncertainties (including correlated) on microlensing, physical, *and* nuisance parameters

2) Can incorporate all degenerate solutions probabilistically.

Clanton & Gaudi 2017

Suzuki et al. 2017
Probabilistic Populations

Examples from Kepler (Wolfgang et al. 2015, 2016): sub-Neptune compositions and mass-radius relations

- Allows for a distribution of masses at a given radius as is motivated by observations and theory.
- Can distinguish between scatter due to measurement uncertainty and astrophysical scatter in the planet population.
- No binning necessary; also includes upper limits.
Thank you - Thoughts?

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