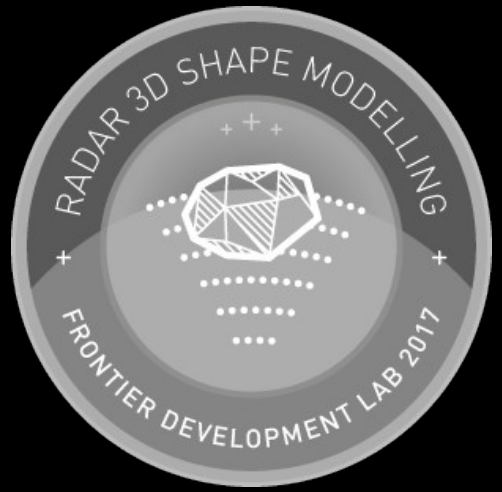
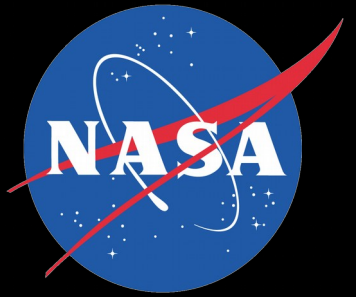
Using Bayesian Optimization to Find Asteroids' Pole Directions

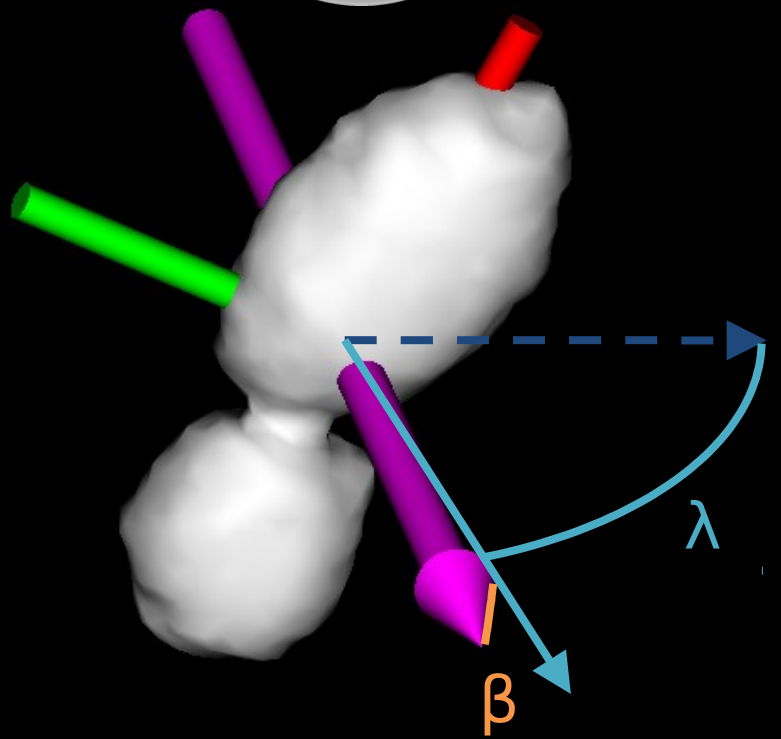
Sean Marshall (Arecibo Observatory & University of Central Florida); Adam Cobb, Yarin Gal, Grace Young (University of Oxford); Chedy Raïssi (INRIA); Michael Busch (SETI Institute); Agata Rożek (University of Kent); Riley McGlasson (Macalester College)



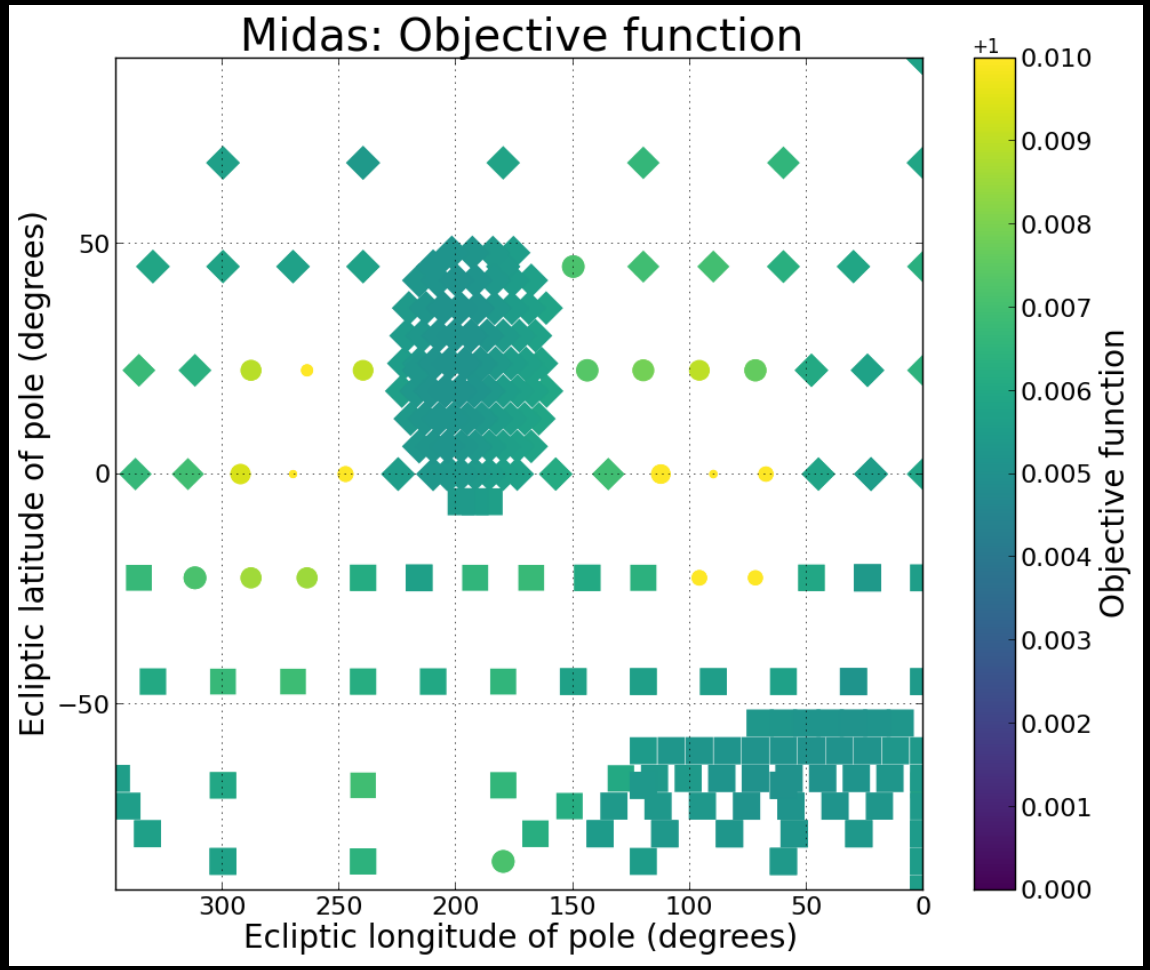


Finding the Rotation State

- Pole direction: What part of the sky does the rotation axis point toward?
  - Defined by ecliptic longitude (λ) and latitude (β)
- Need to know that to do shape modeling properly



Old-Fashioned Grid Search

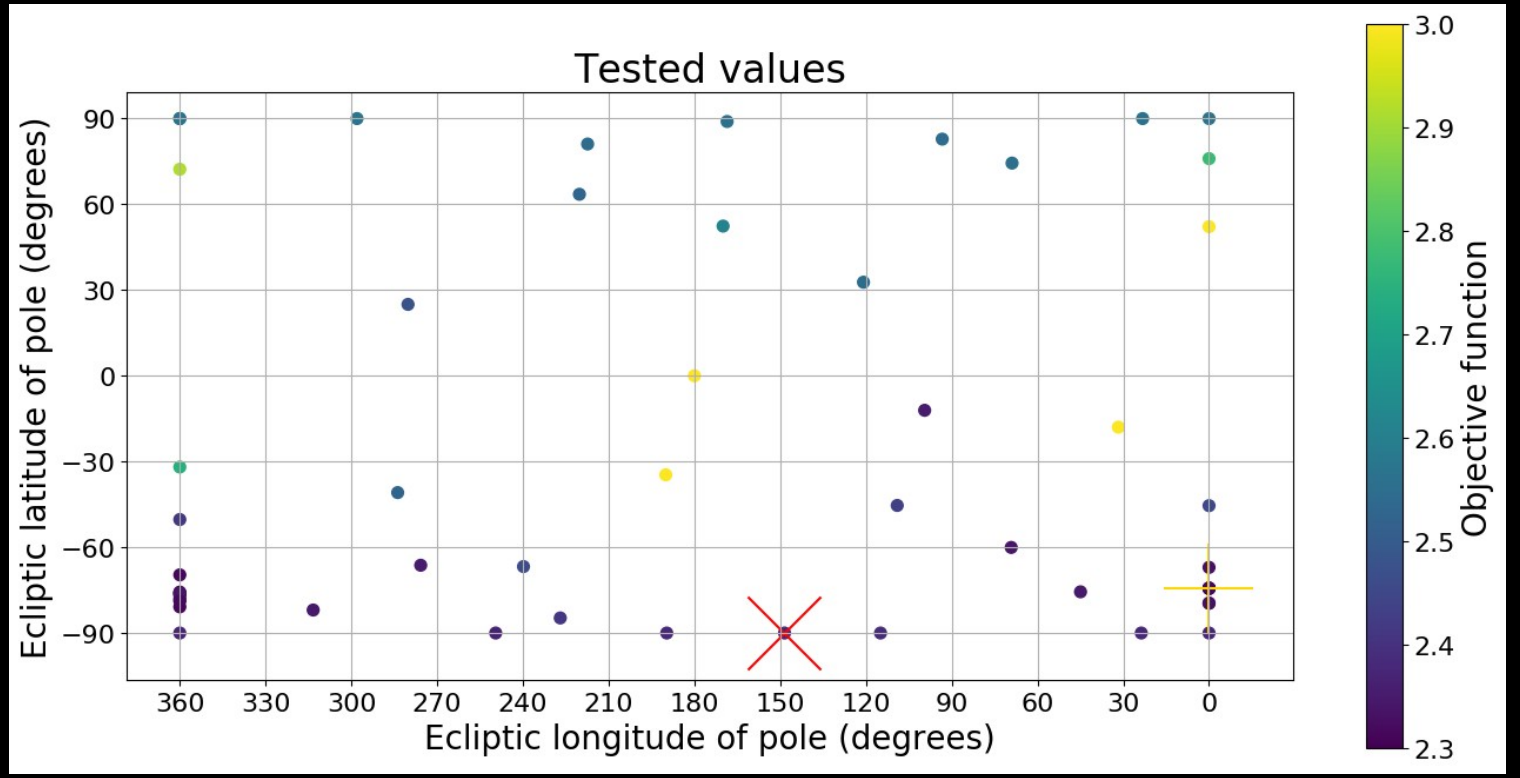


Choose all test points *before* starting each set of models

But usually, run multiple sets

Shape modeling of 1981 Midas: McGlasson et al., in prep

Bayesian Optimization on a Plane



Test on (162421) 2000 ET70 (Raïssi et al. 2016)

RADAR 3D SHAPE MODELLING
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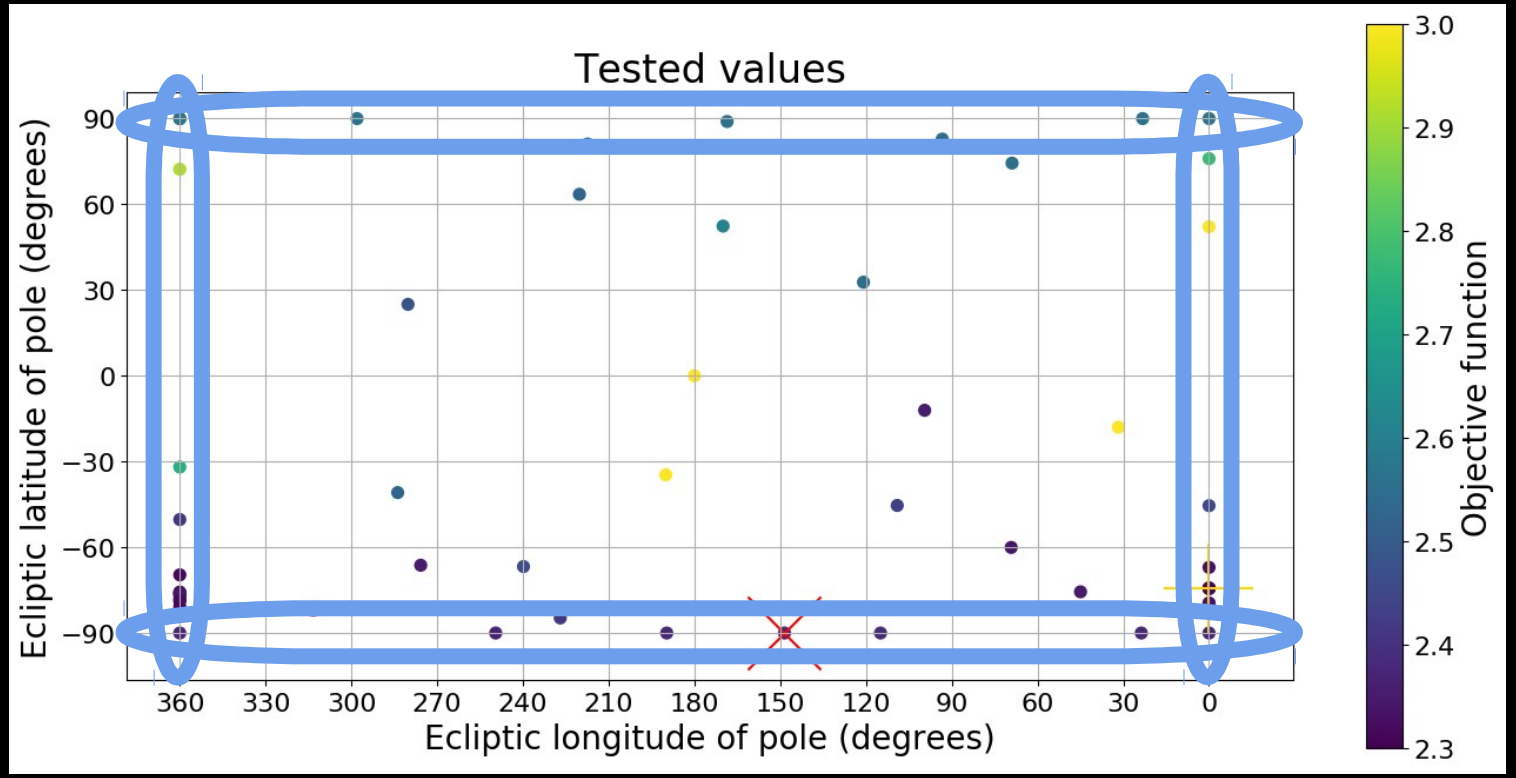
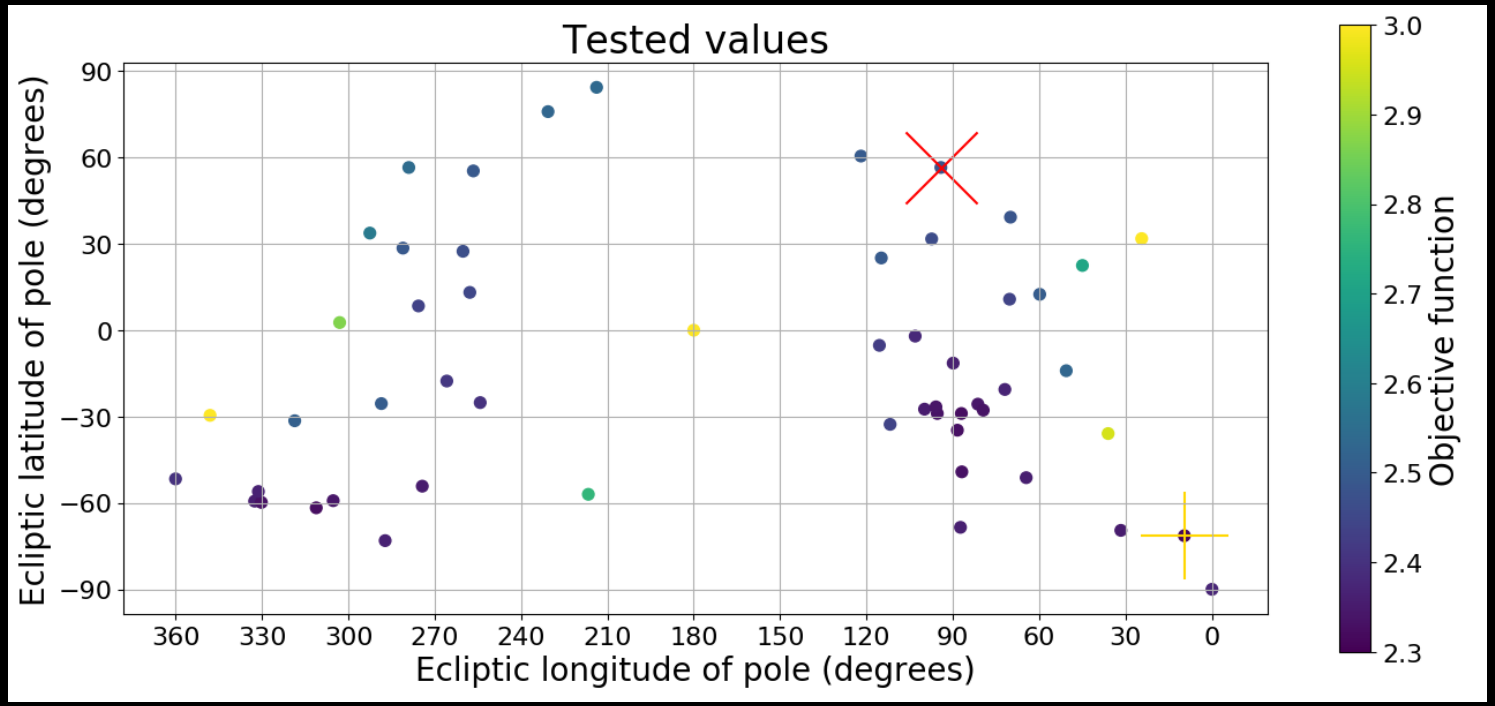
Bayesian Optimization on a Plane



Test on (162421) 2000 ET70 (Raissi et al. 2016)

We want to measure distance *on a sphere*

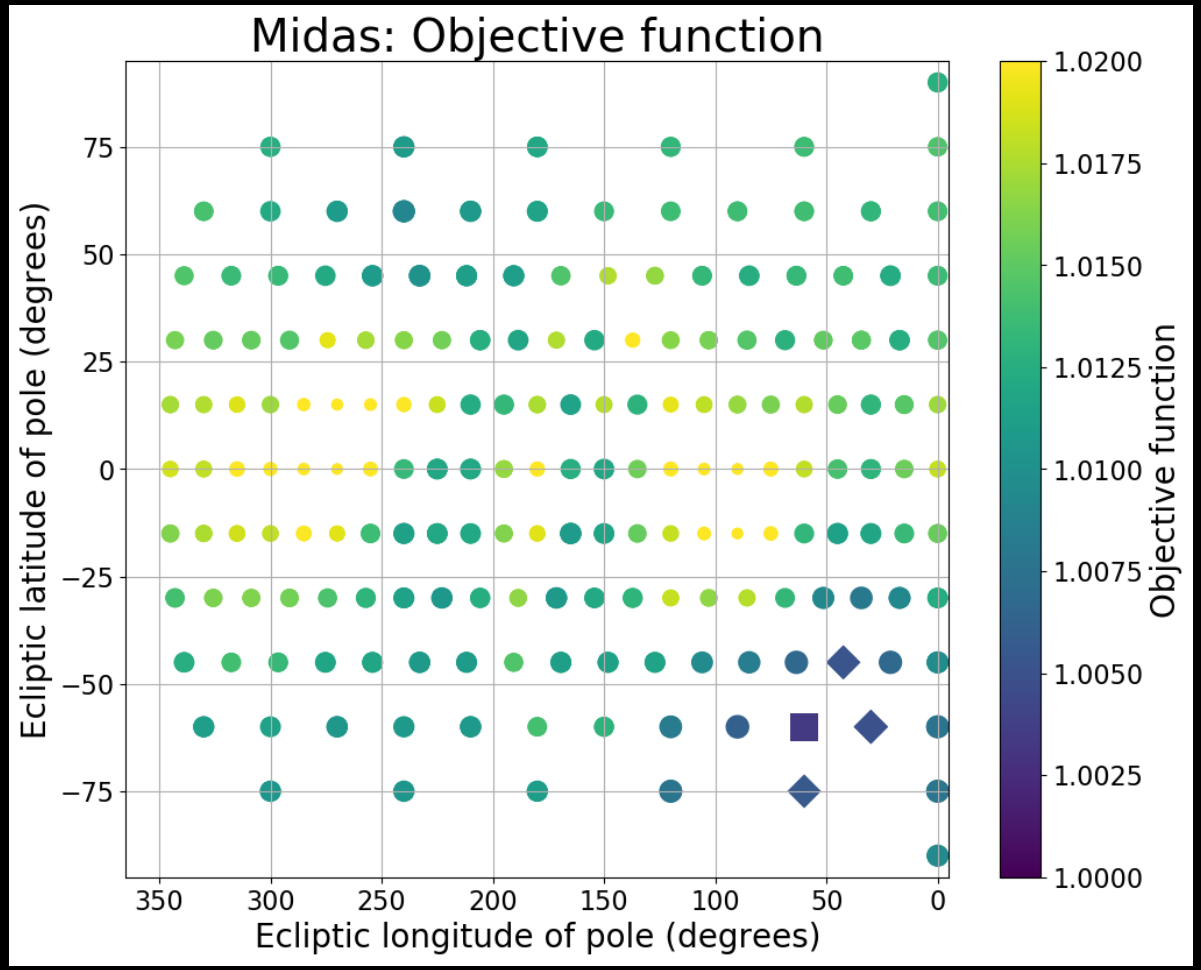
Bayesian Optimization on a Sphere



Test on (162421) 2000 ET70 with Spearmint (Snoek et al., 2012)

Bayesian optimization in spherical coordinates first considered by Carr, Garnett, and Lo (2016)

Old-Fashioned Grid Search



Test on 1981 Midas

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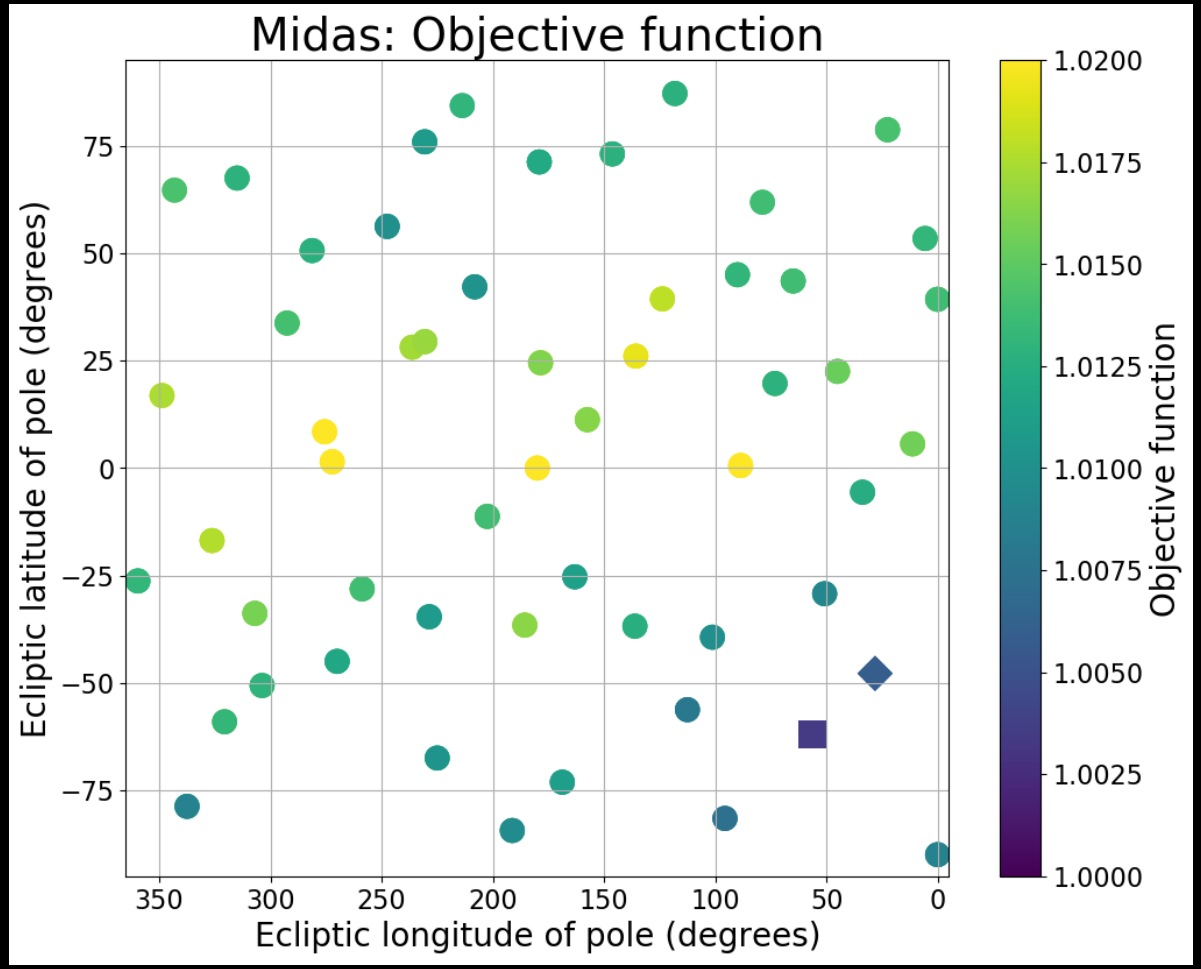
Bayesian Optimization on a Sphere



Test on 1981 Midas with Spearmint

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Acknowledgments

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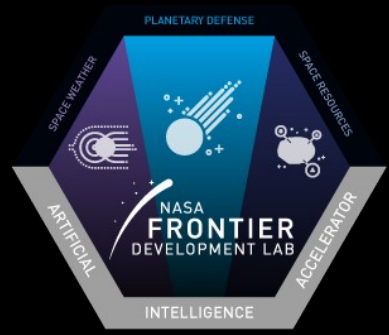
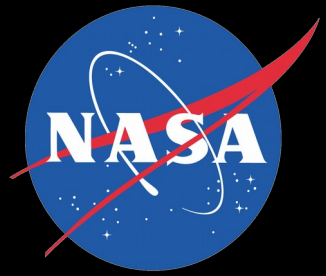
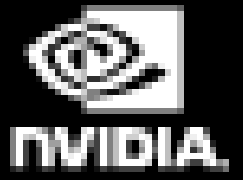


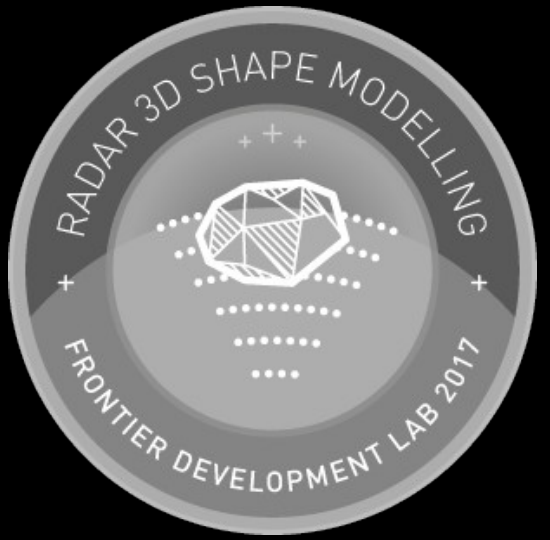




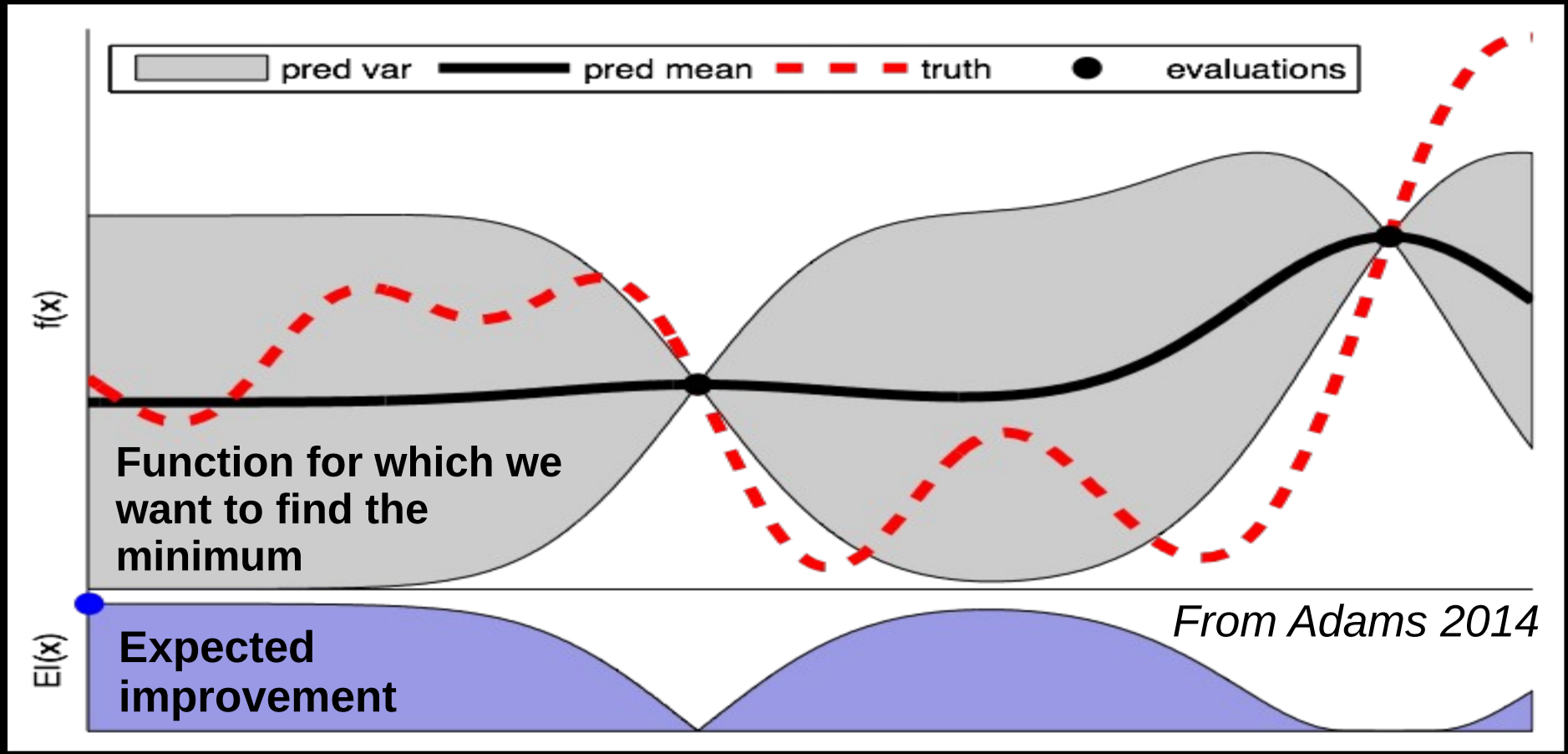
Backup slides

Future Work

- Experiment with initialization settings and convergence criteria
- Use latest version of Spearmint
- Test more asteroids
- Write up paper
- Publish code and documentation
- Apply Bayesian optimization to other problems, such as thermal modeling



Bayesian Optimization (1D example)



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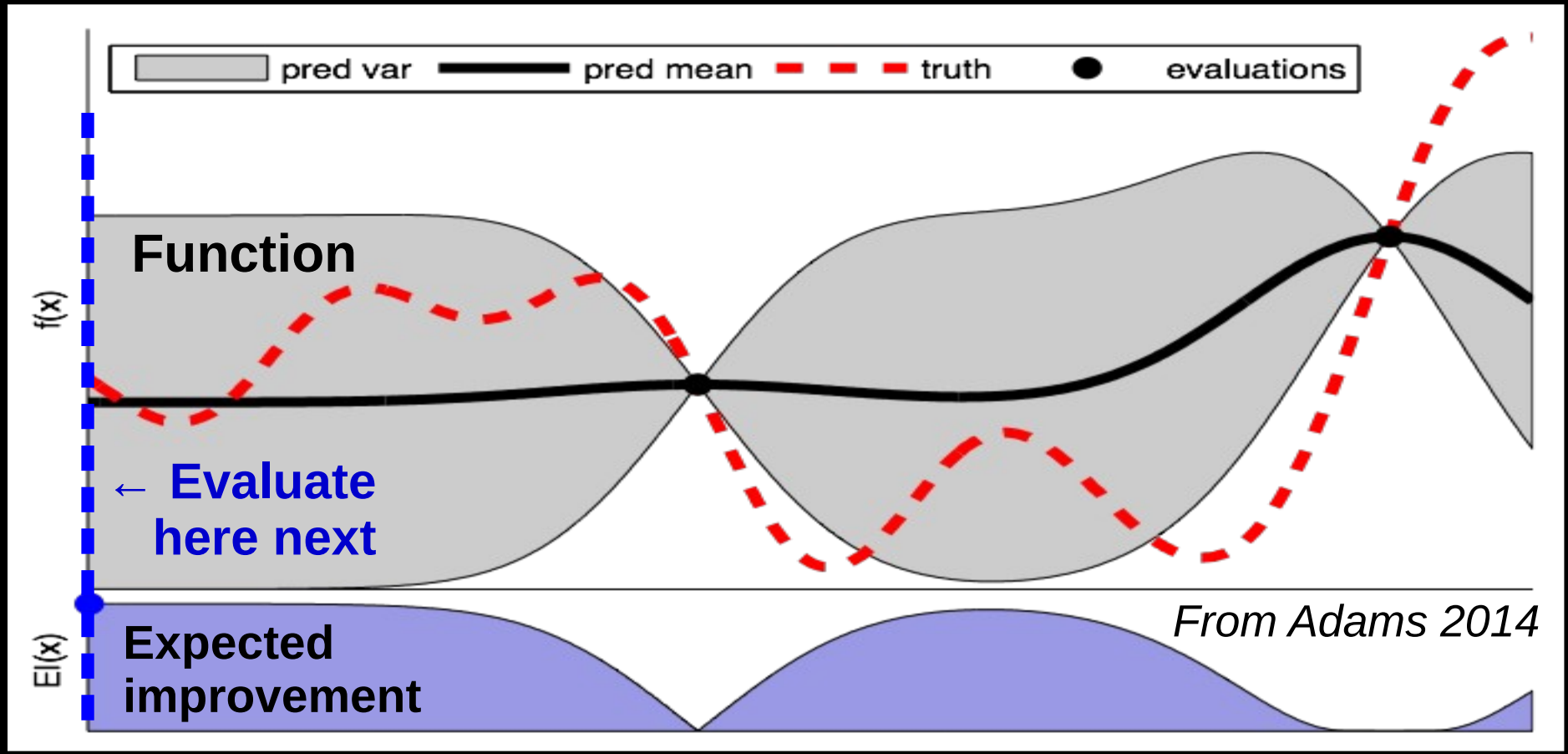
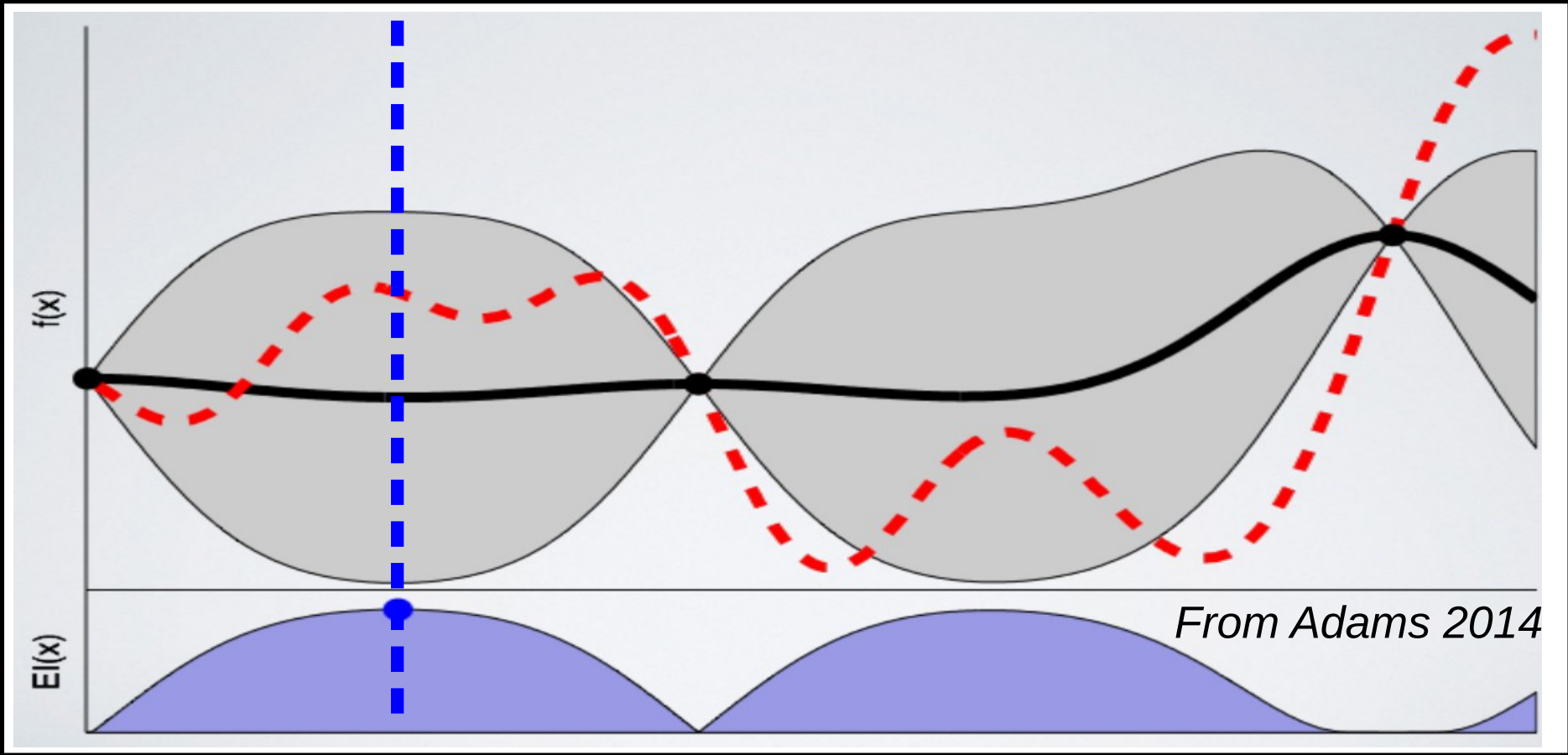


Bayesian Optimization



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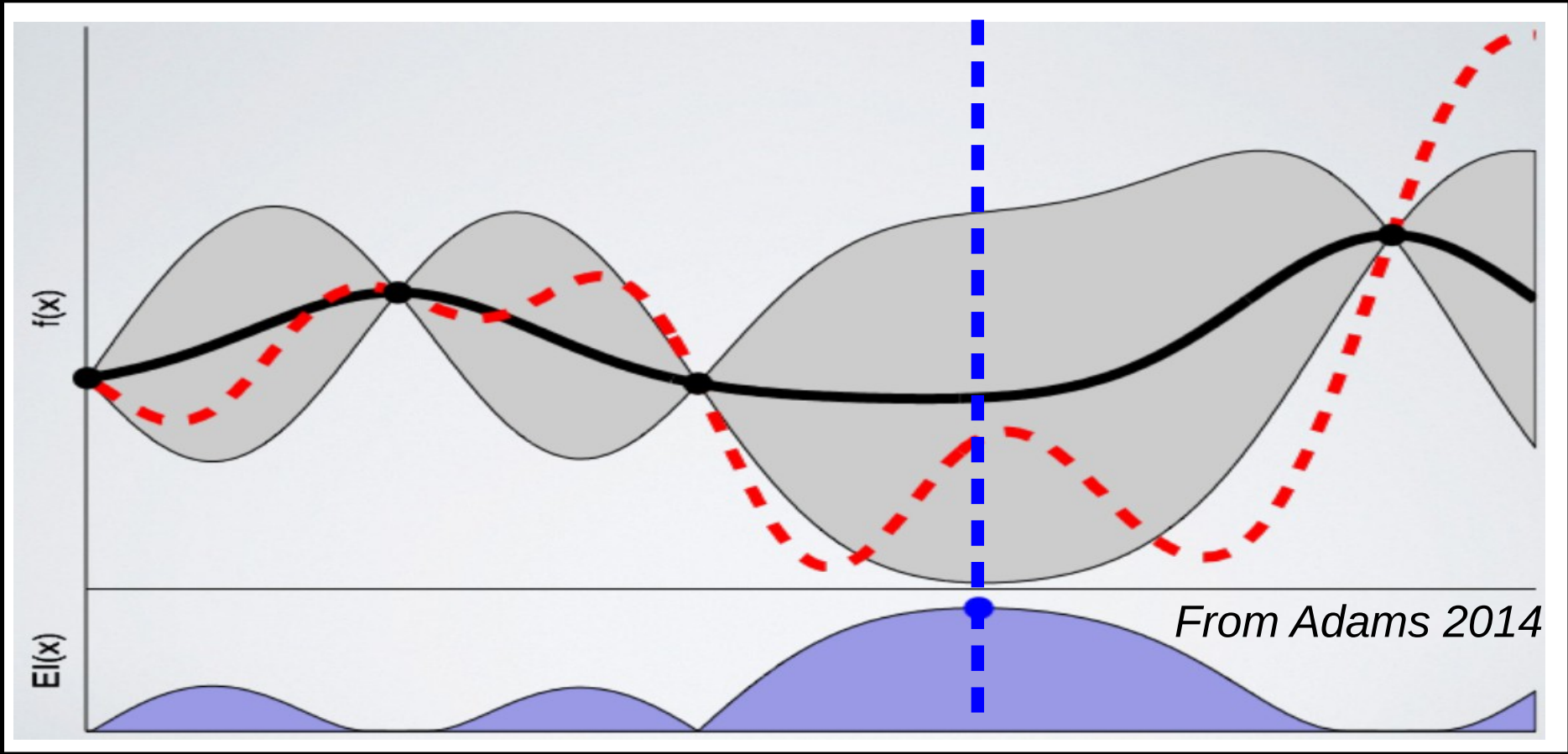

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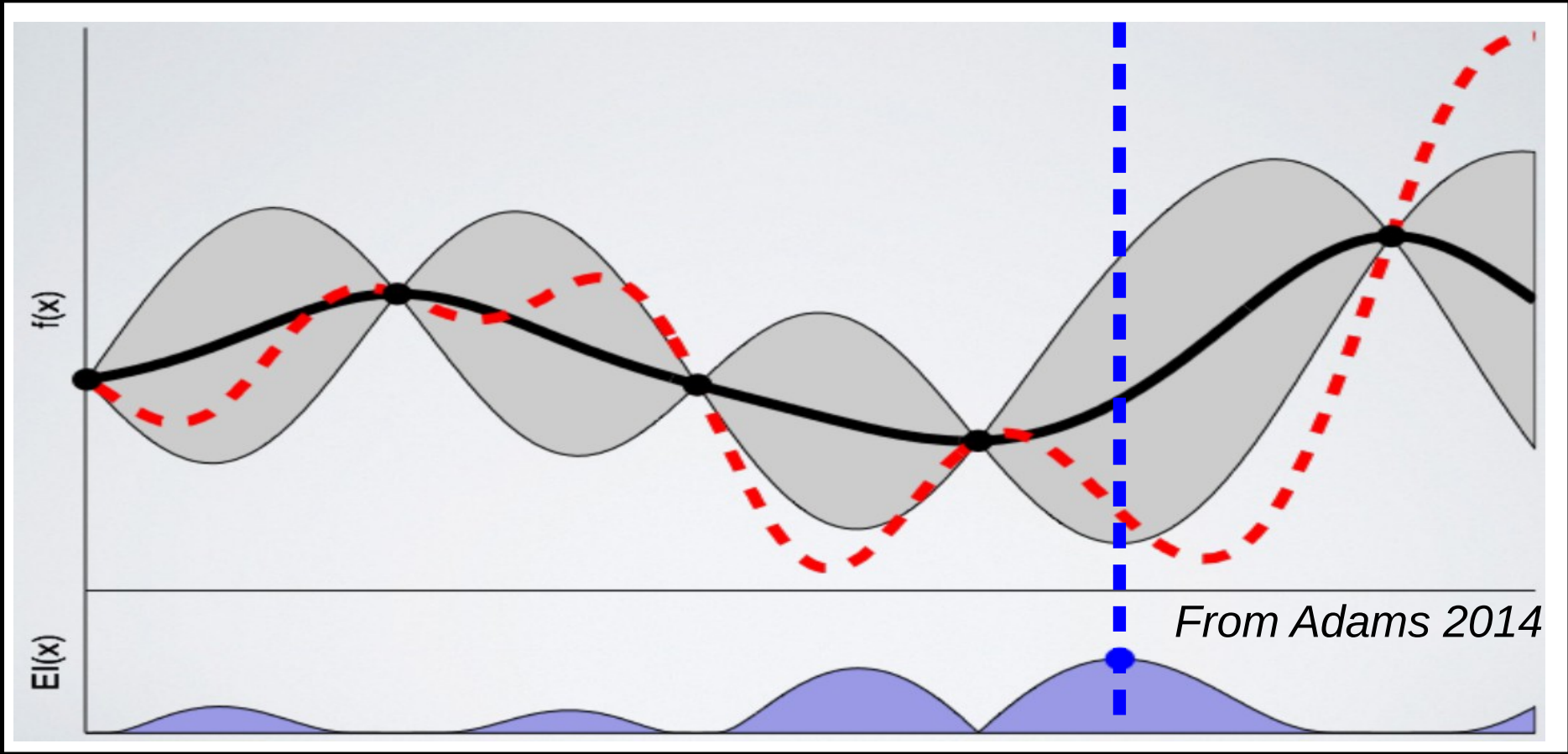

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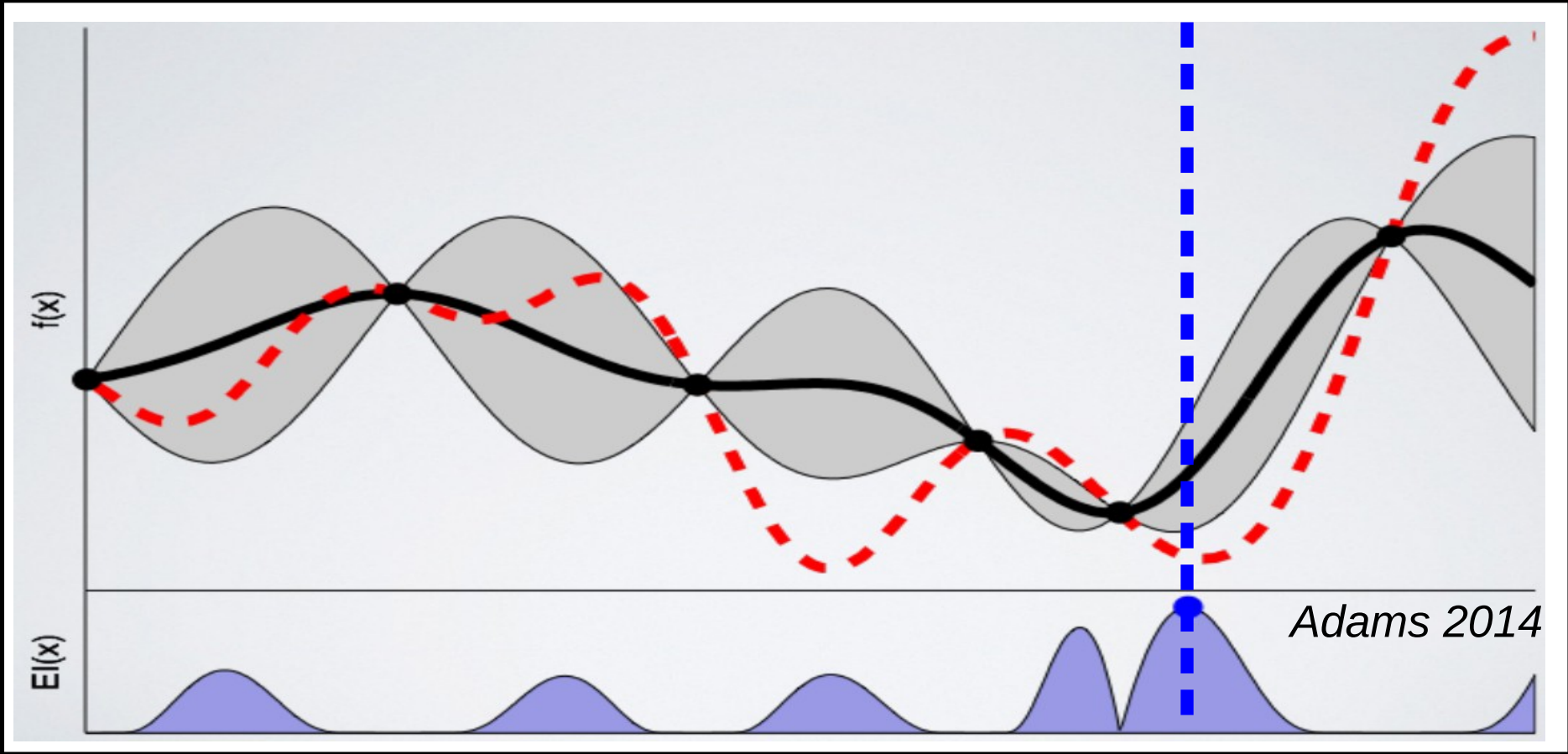

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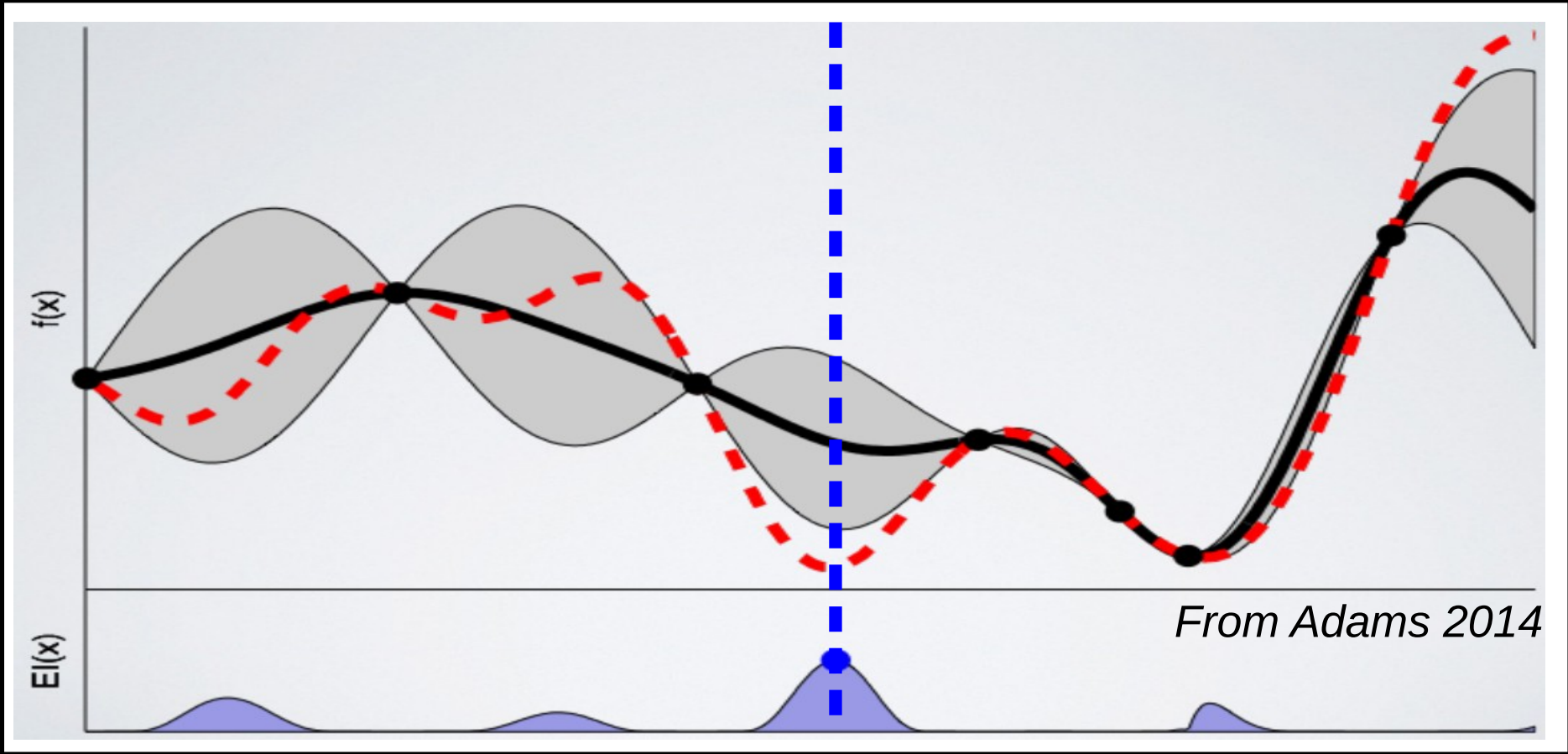

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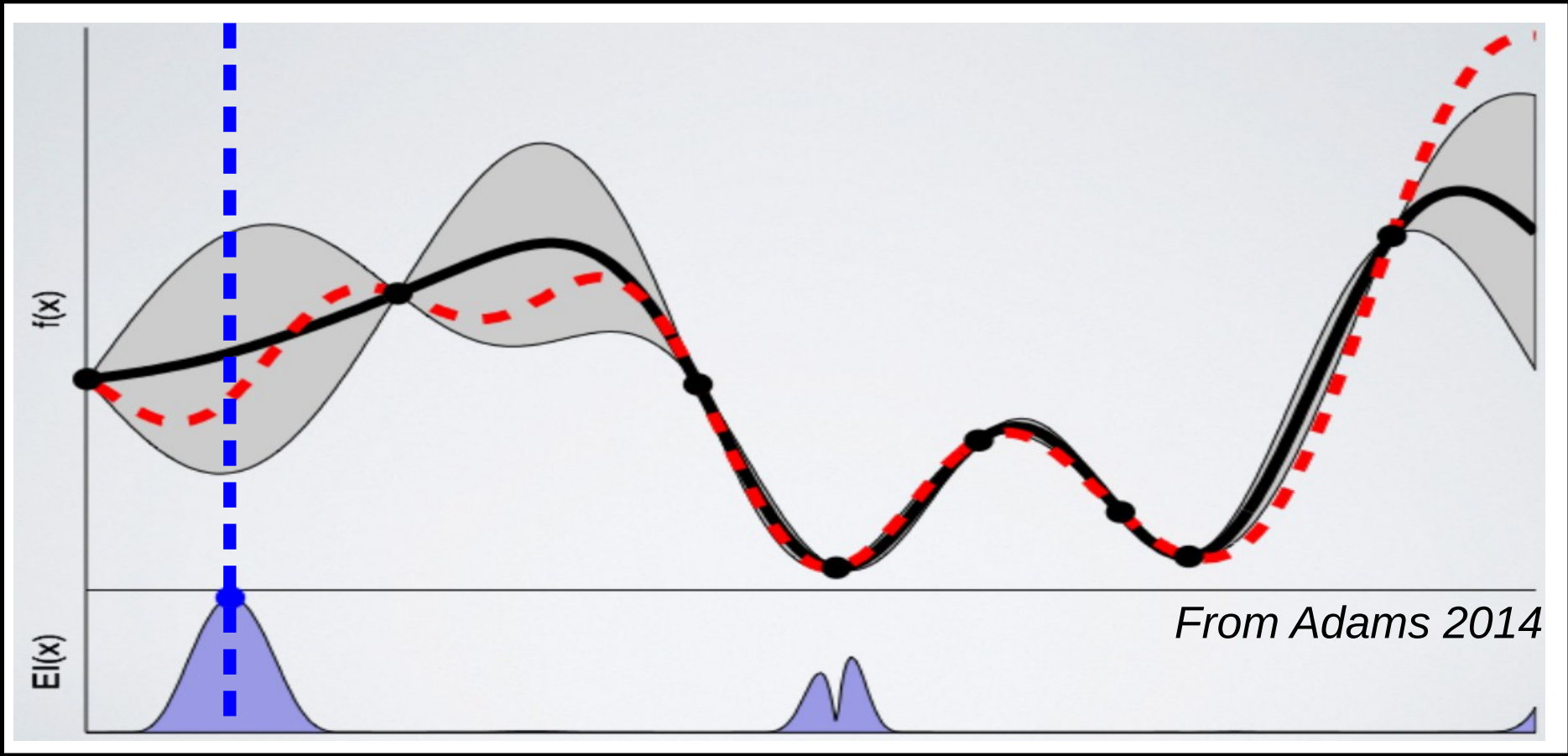


Gaussian Processes

- GP is defined by its mean and covariance:

$$\mathbf{f}(\mathbf{x}) \sim \mathcal{GP}\left(\boldsymbol{\mu}(\mathbf{x}), \mathbf{K}(\mathbf{x}, \mathbf{x}')\right)$$

Mean function

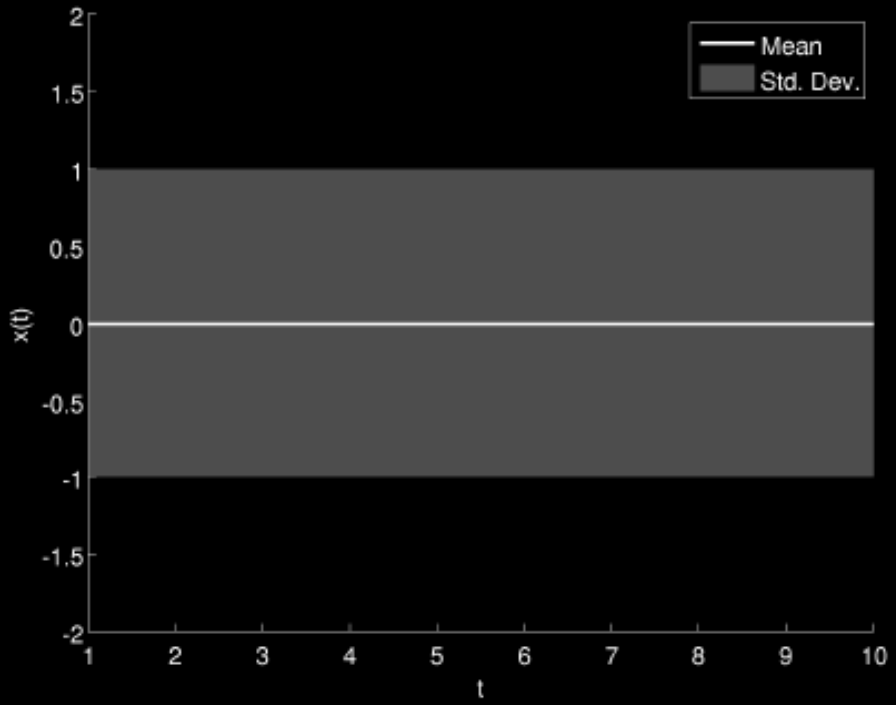
Covariance function

Example covariance: Squared exponential

$$k_{\mathrm{SE}}(x_1, x_2) = h^2 \exp\left[-\frac{(x_1 - x_2)^2}{2\lambda^2}\right]$$

Gaussian Processes

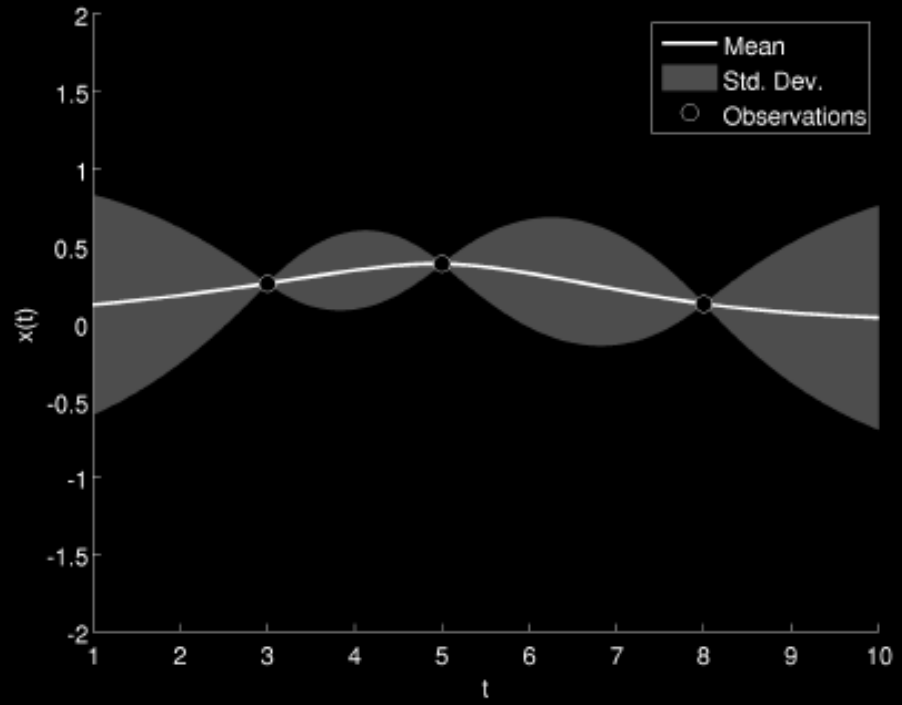
- Prior (before observations):



From Roberts et al. 2012

Gaussian Processes

- After three observations:



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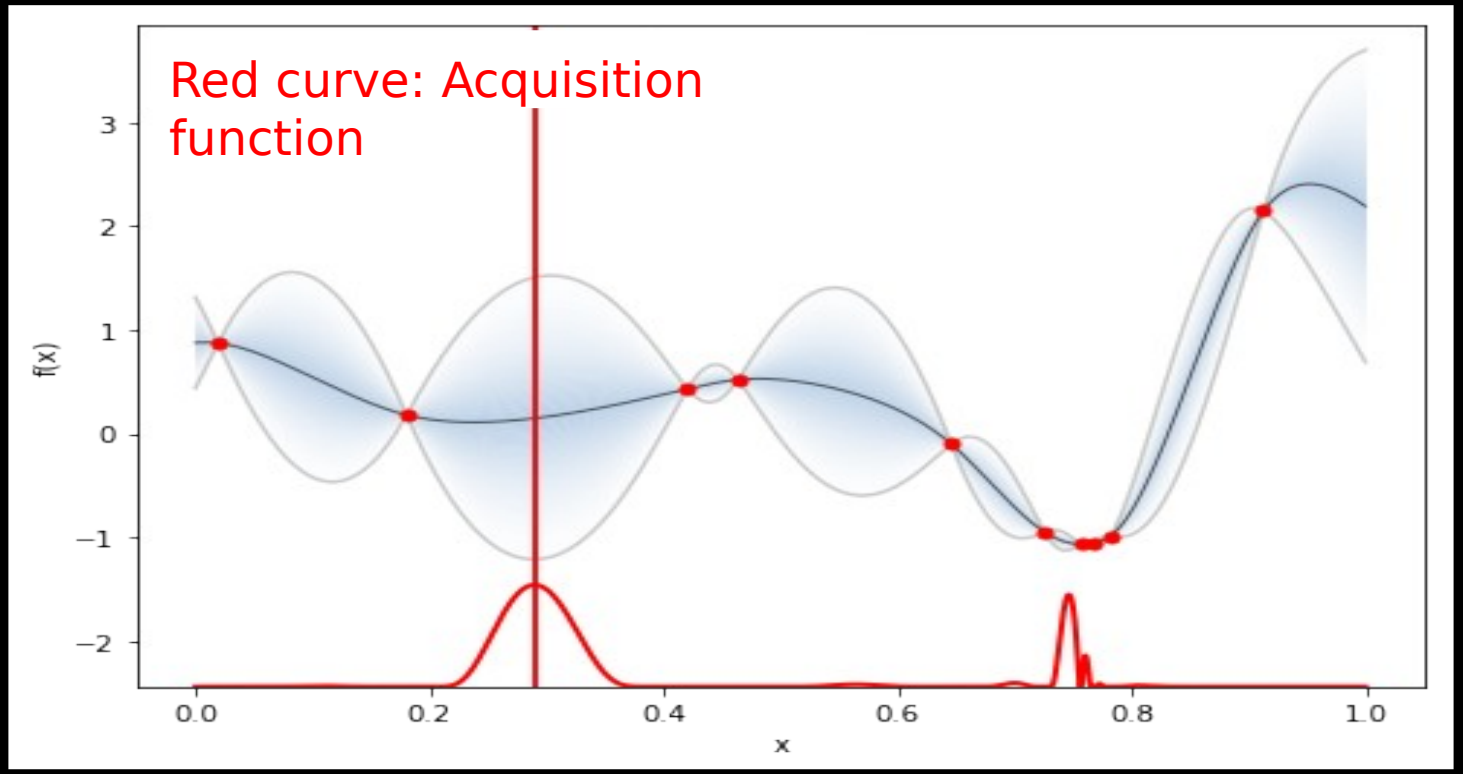
Bayesian Optimization



Finding a minimum automatically, without human oversight

1D example; from Adam Cobb using GPyOpt