Time delay estimation

(case of gravitationally-lensed quasars)

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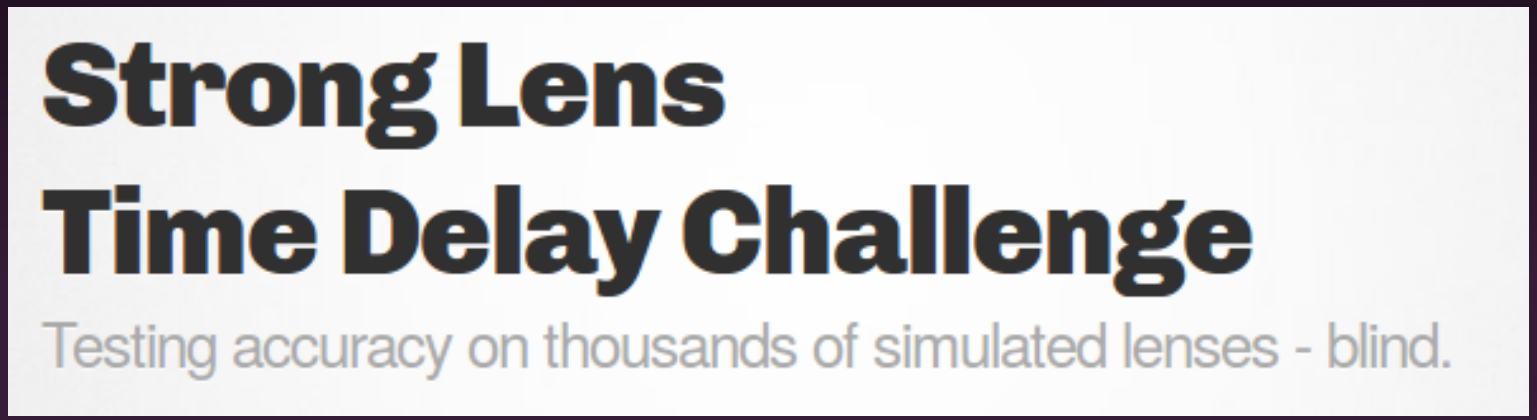
Outline

- Question
- Dataset
- Main idea
- What we tried
  - Unsuitable methods
  - (probably) Suitable methods
- Current state
- Way to improvement

Question - Original



TimeDelayChallenge.org

Question - Machine learning approach

How much do the ground truth information mean in terms of accuracy?

OR:
How limiting are the intrinsic uncertainties?

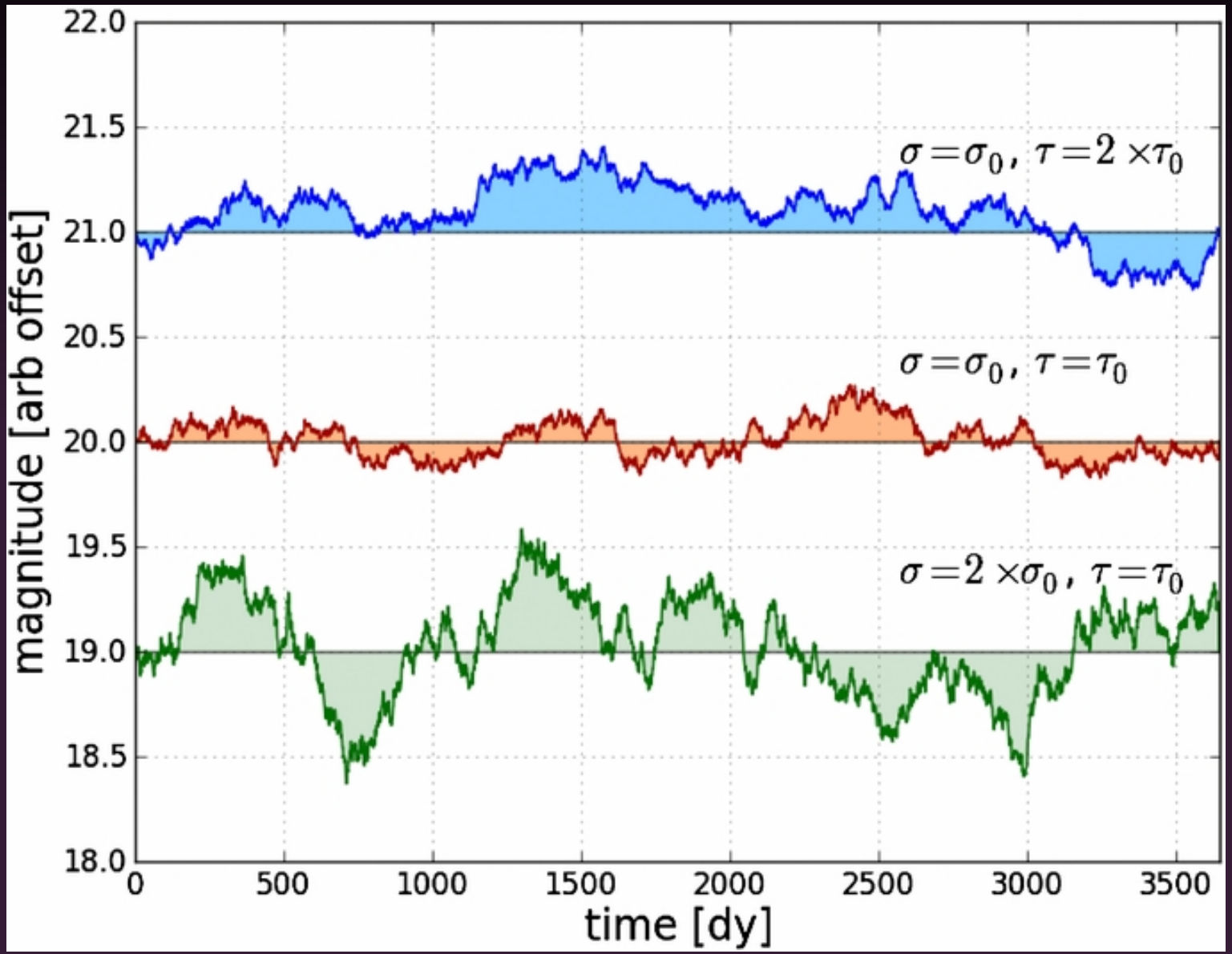
Meta question:
What does this mean in terms of the Hubble constant?

Dataset - Inroduction

Realistic mock observed lensed quasar light curves

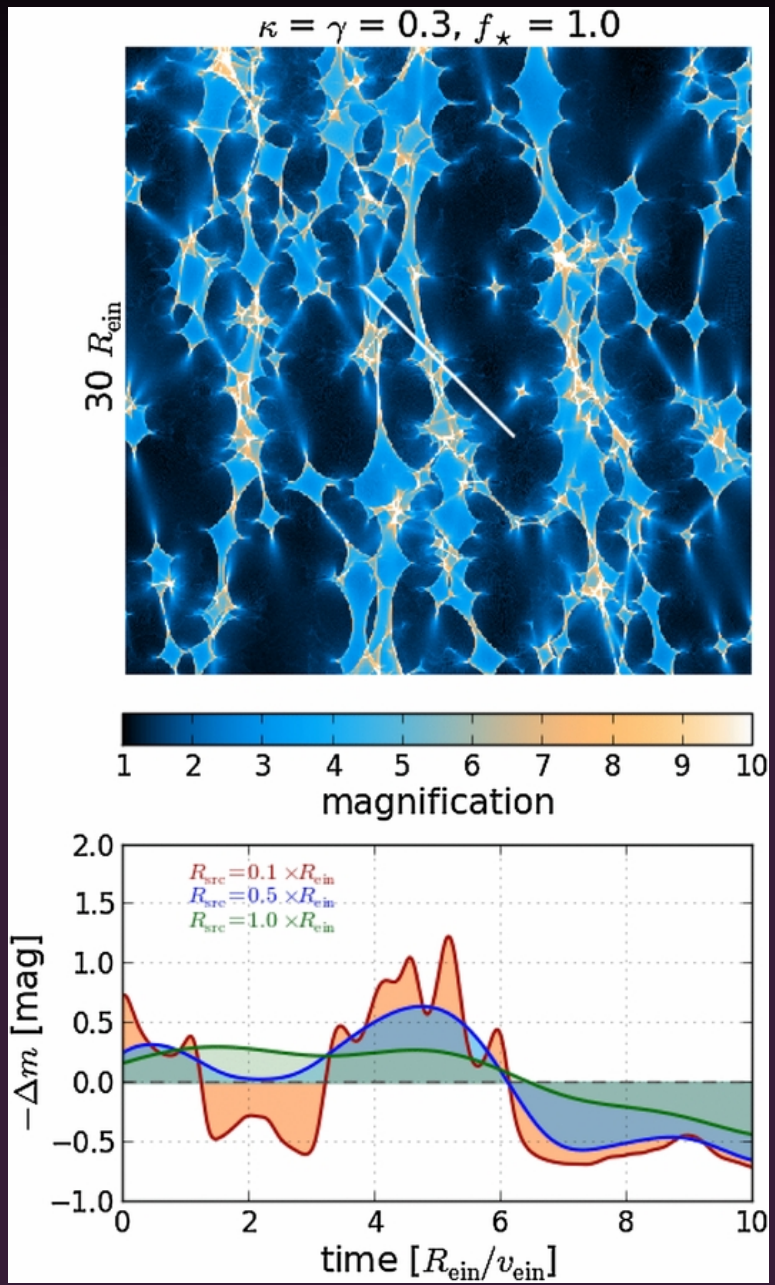
Dataset - AGN variability

Dobler+2015



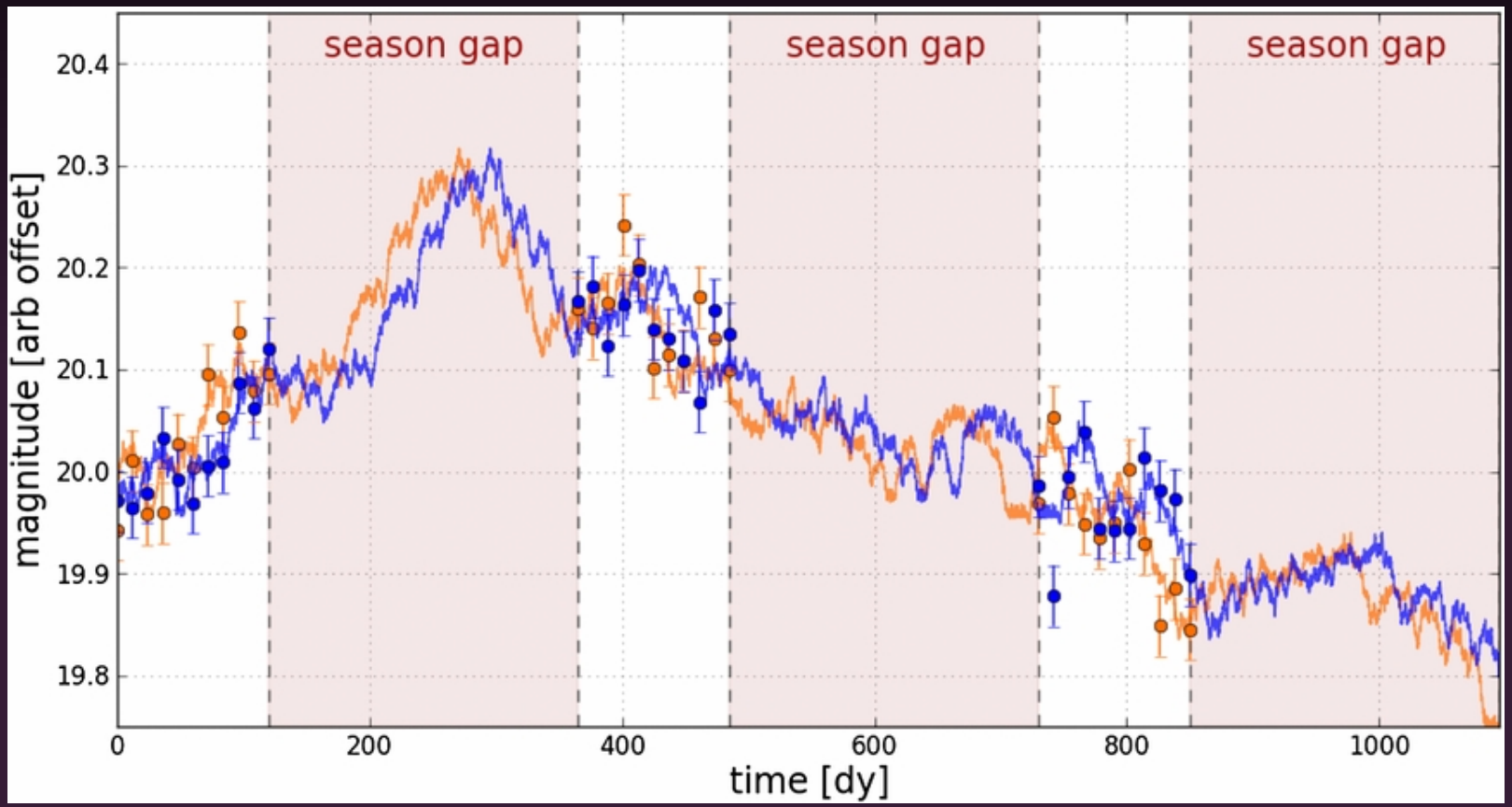
Dataset - Microlensing effects

Dobler+2015



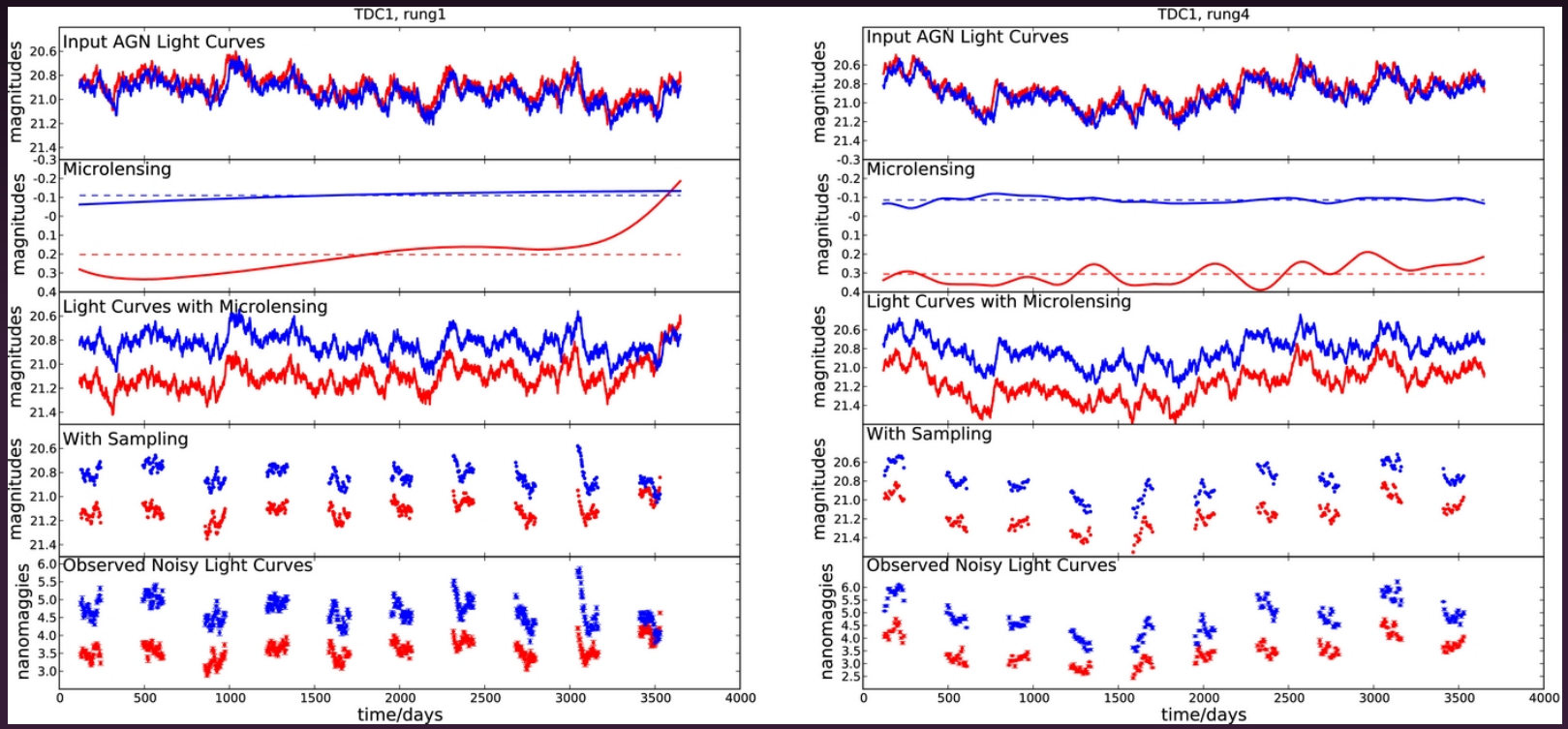
Dataset - Observational effects

Dobler+2015



Dataset

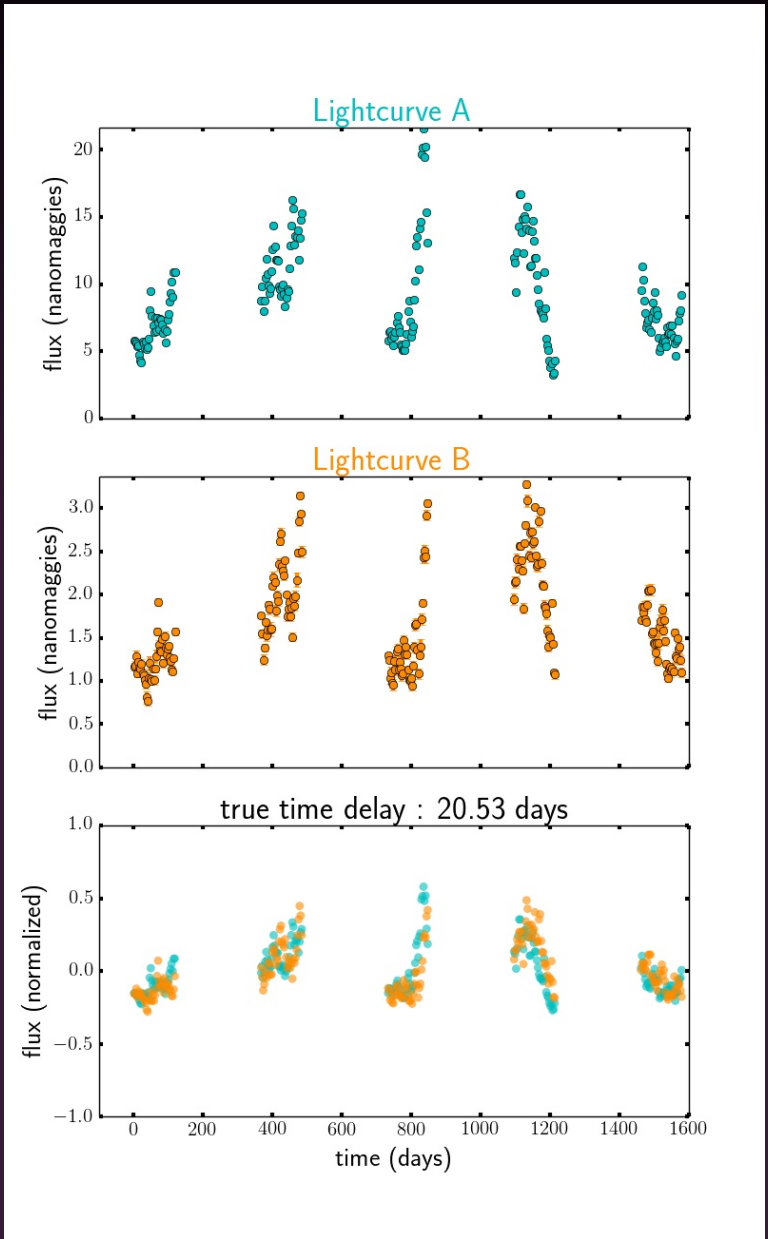
Liao+2015

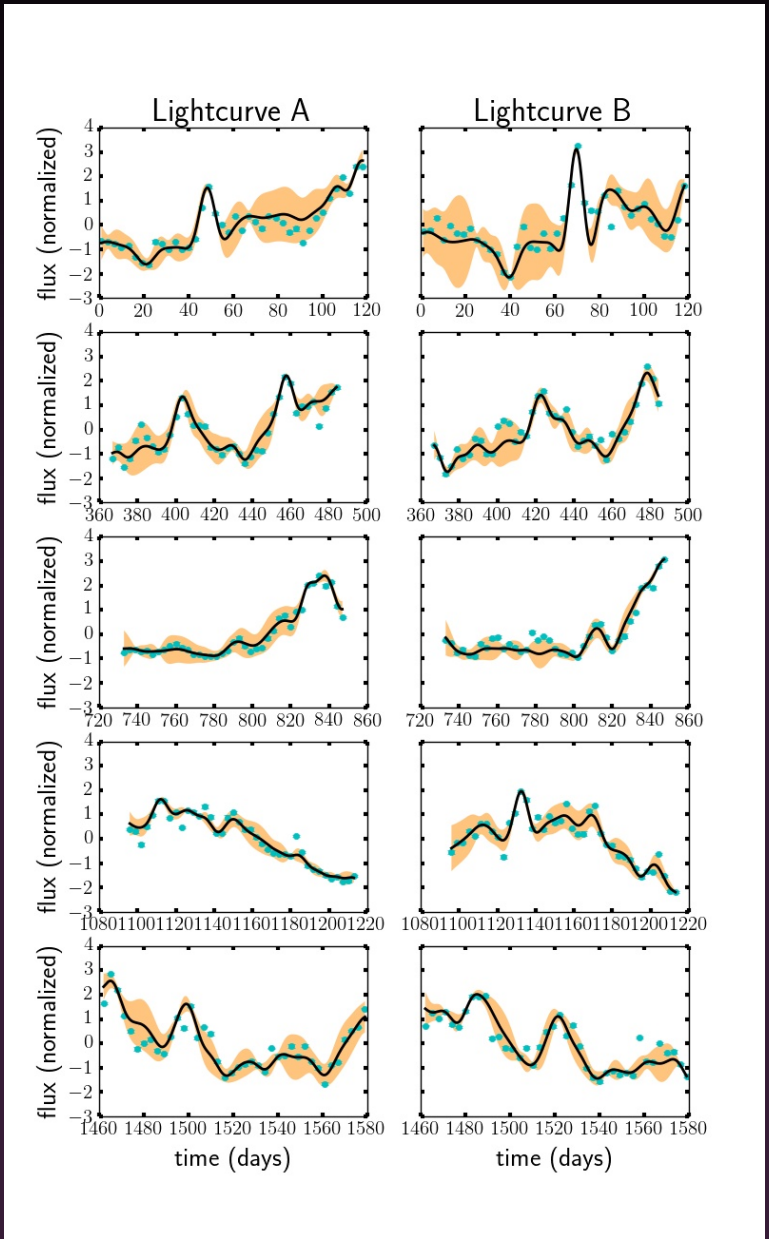


Main idea

- **Smooth** and **interpolate** evenly sampled data
- **Compare** two light curves of each window for dt between 0 and window length
  - `scipy.signal.correlate`
  - MSE
- Find the **best timeshift** for each window
  - `max(correlate)`
  - `min(MSE)`
- **Compare** estimated best dt of different windows of the same pair
  - `np.median(dt[window])`
  - `np.mean(dt[window])`
  - `np.std(dt[window])`
  - weighted mean (based on absolute correlate value)
- Use a **clustering** algorithm to reduce the noise
- Apply a **regression** method to the clustered values

Dataset - smooth (Gaussian processes)





Dataset - smooth (Gaussian processes)

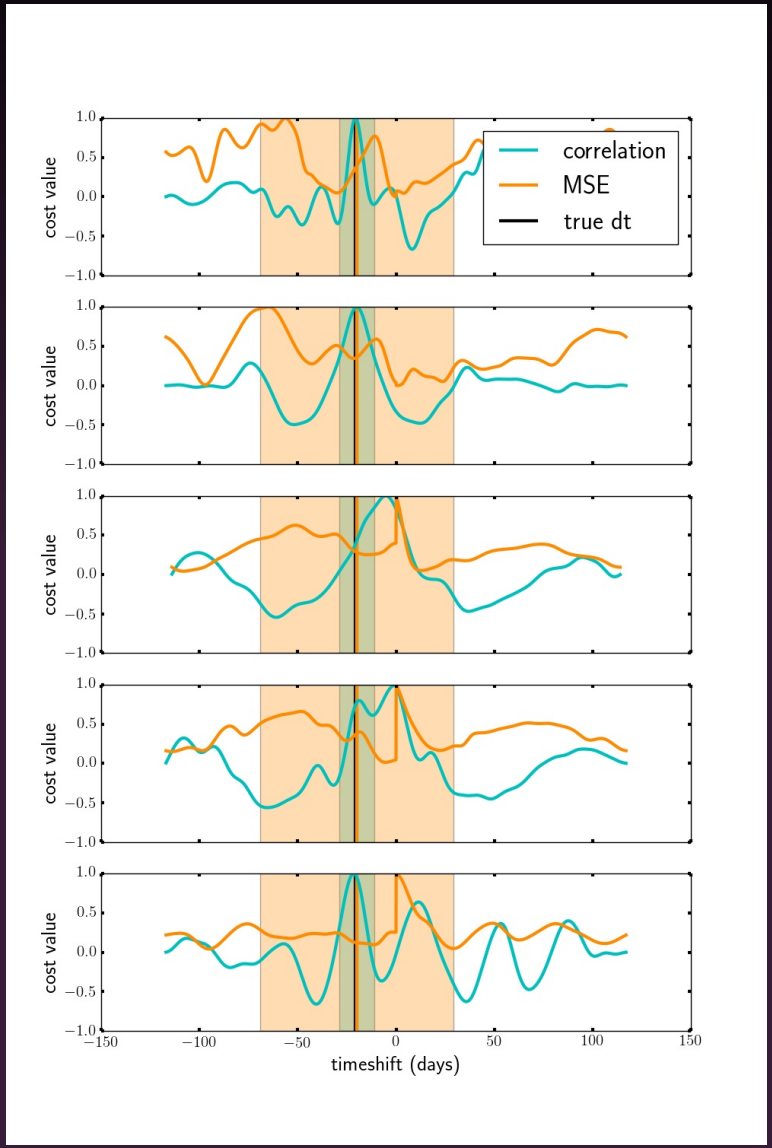
```
gp = GaussianProcess(corr = "squared_exponential",
                     regr = "quadratic",
                     theta0 = sigma,
                     thetaL = tau,
                     thetaU = tau,
                     nugget = (dy / y) ** 2,
                     random_start=500)


gp.fit(X, y)

y_pred, MSE = gp.predict(x, eval_MSE=True)
```

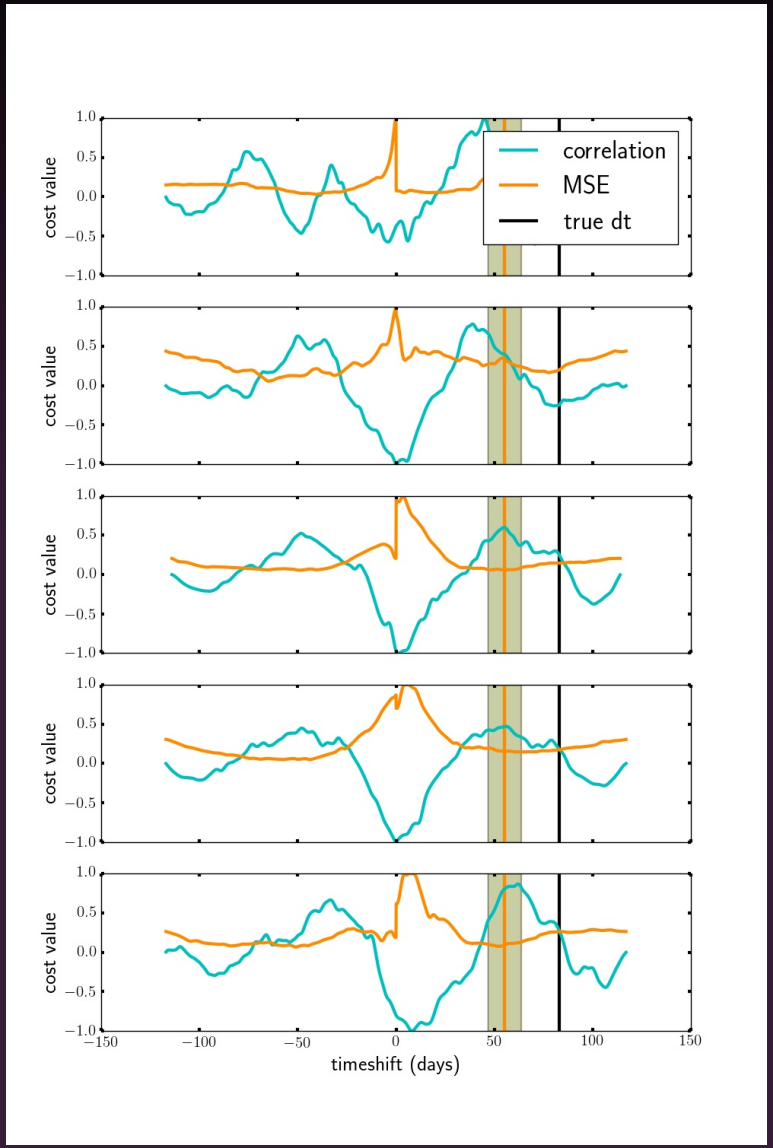
Comparison - What we tried ... and failed

- Lomb-Scargle periodogram on raw, unevenly-sampled data
- FFT on even resampling of the smooth models

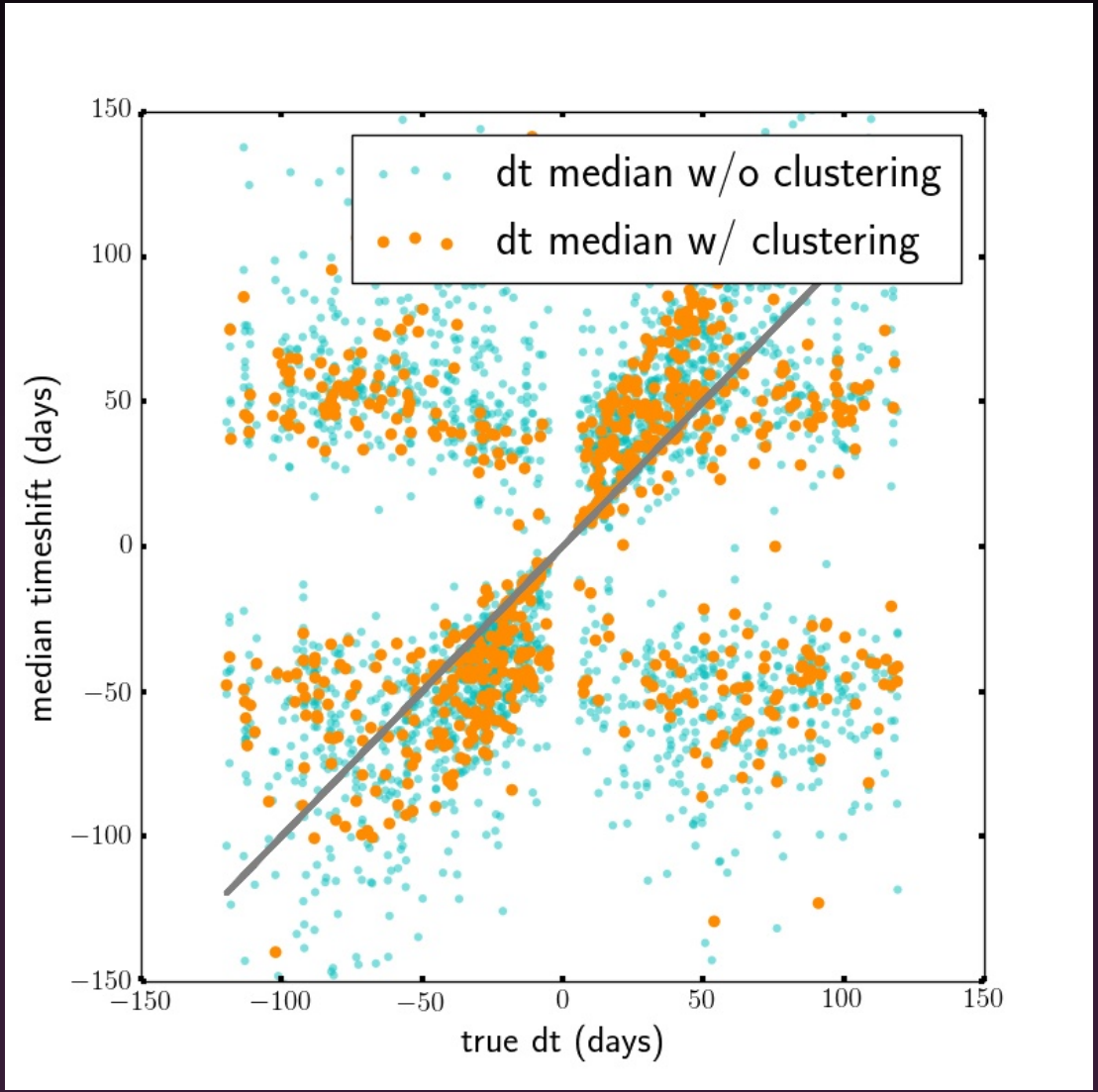
Idea: phase (angle of the complex FFT value) of the highest-amplitude frequency would correlate with the real dt.
Problem: Inside each window, the signal is highly a-periodic, which probably introduces a lot of noise.

Comparison - What we tried ... and succeeded





Reduce noise - clustering



Way to improvement

- Error analysis
- Regularized linear regression on correlation arrays
- Unsupervised learning
- Neural network

Future progress

Follow the project on GitHub:
https://github.com/asadisaghar/TimeDelay