Mphil to PhD upgrade talk, 12 of Dec 2019

Potential of RNNs for modelling Transit Light Curves

Supervisors: - Ingo Waldmann
- Jan-Peter Muller
- Angelos Tsiaras

More collaborators: Nikolaos Nikolaou, Billy Edwards, Gordon Yip, Quentin Changeat, Giovanna Tinetti

Mario Morvan

Introduction

Acronyms:

LC = Light Curve

RNN = Recurrent Neural Network

LSTM = Long Short-Term Memory (network)

Exoplanets Boom

- In our galaxy: $\mathbf{N_{exoplanets}} \gtrsim \mathbf{N_{stars}}$ [Cassan et al. 2011]

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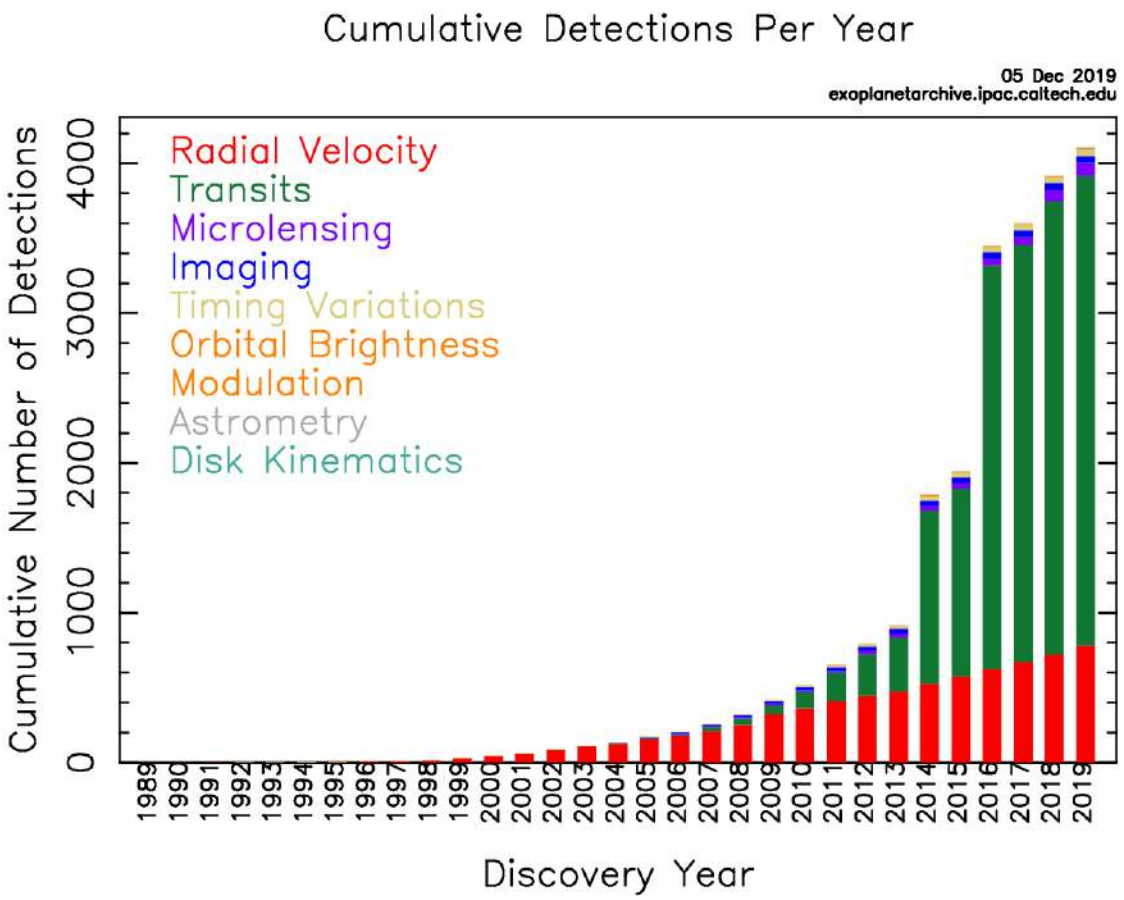
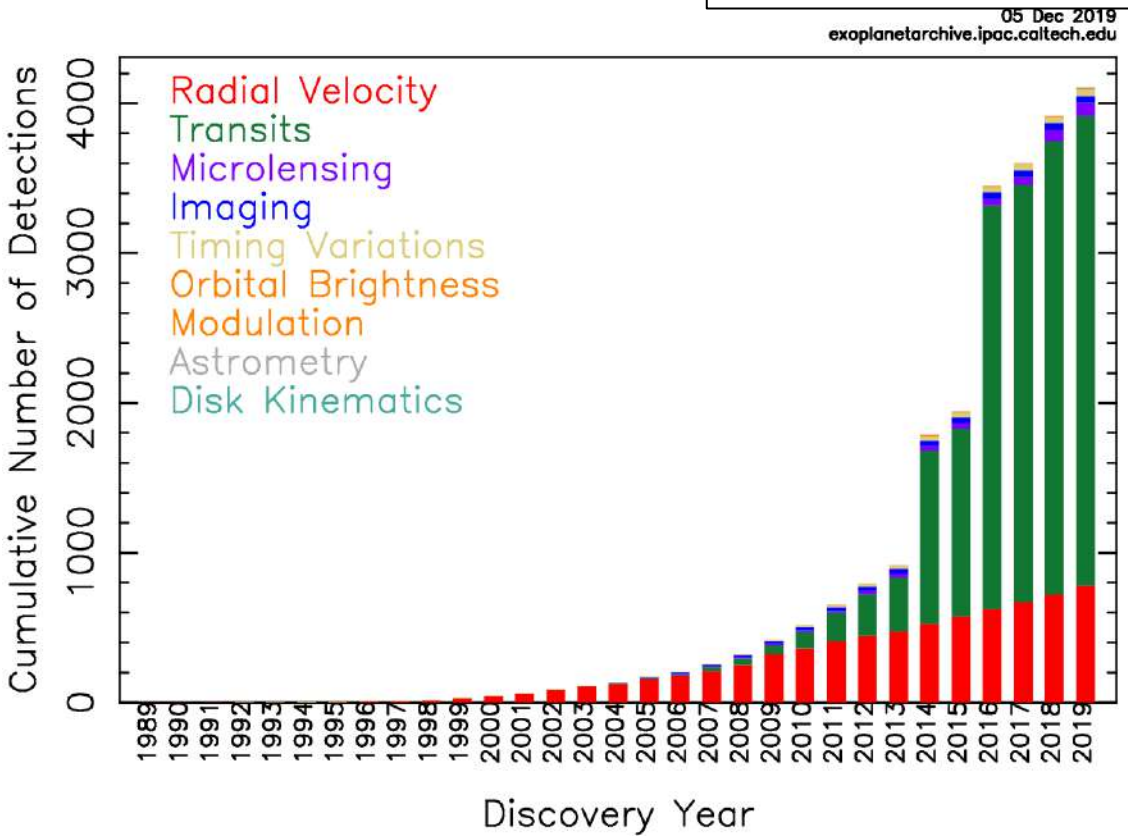
- Exponential discovery rate?



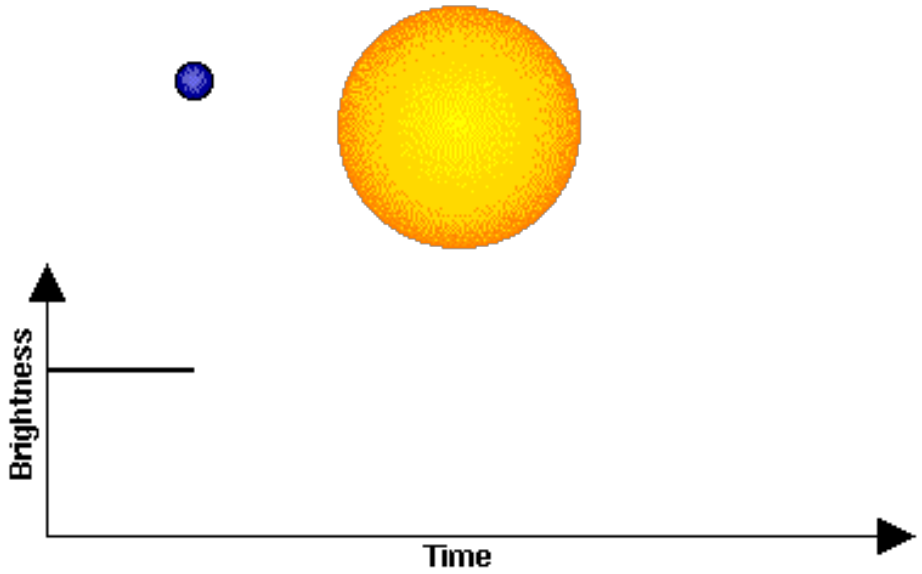
Exoplanets Boom

- In our galaxy: $\mathbf{N_{exoplanets}} \gtrsim \mathbf{N_{stars}}$ [Cassan et al. 2011]
- Exponential discovery rate?

$N(t) = N_0.2^{t/4}$ → 100 years to discover all Milky way planets



Transit method



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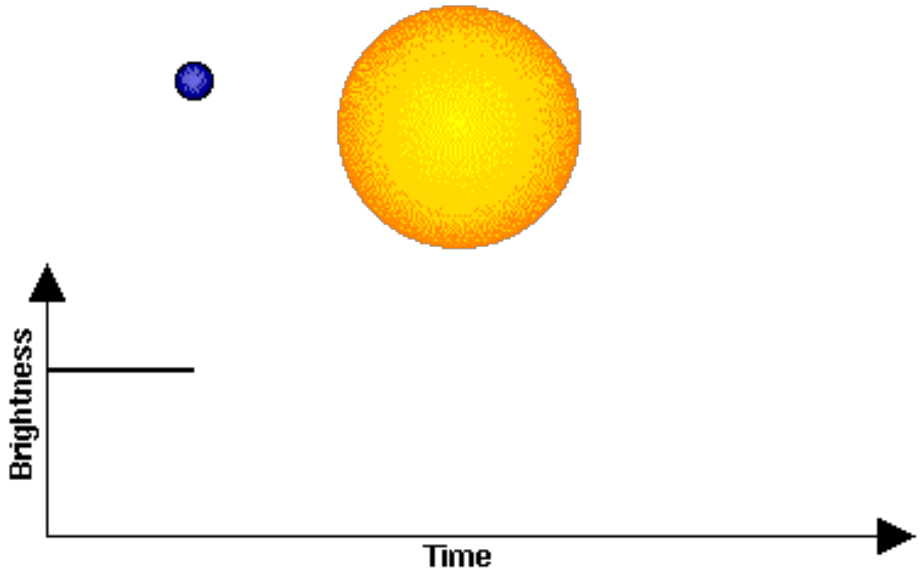

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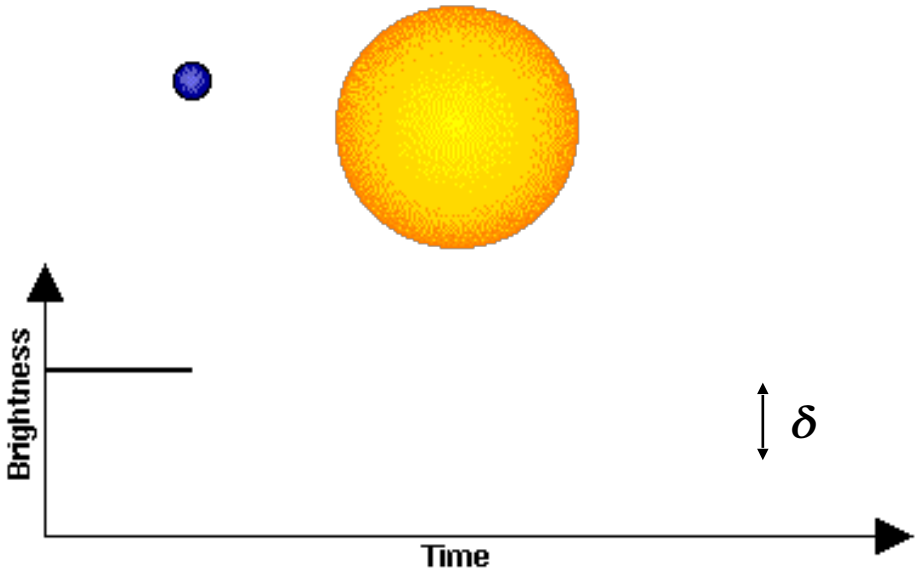
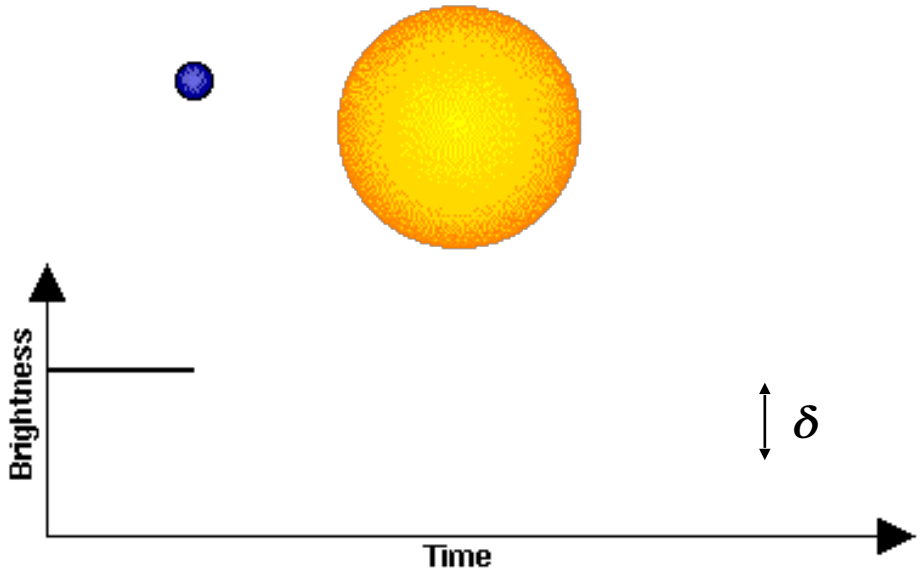


$$F \simeq (1 - \delta)\, F_{star}$$

$$\delta(\lambda) \simeq \left(\frac{R_P(\lambda)}{R_S}\right)^2$$

Transit method



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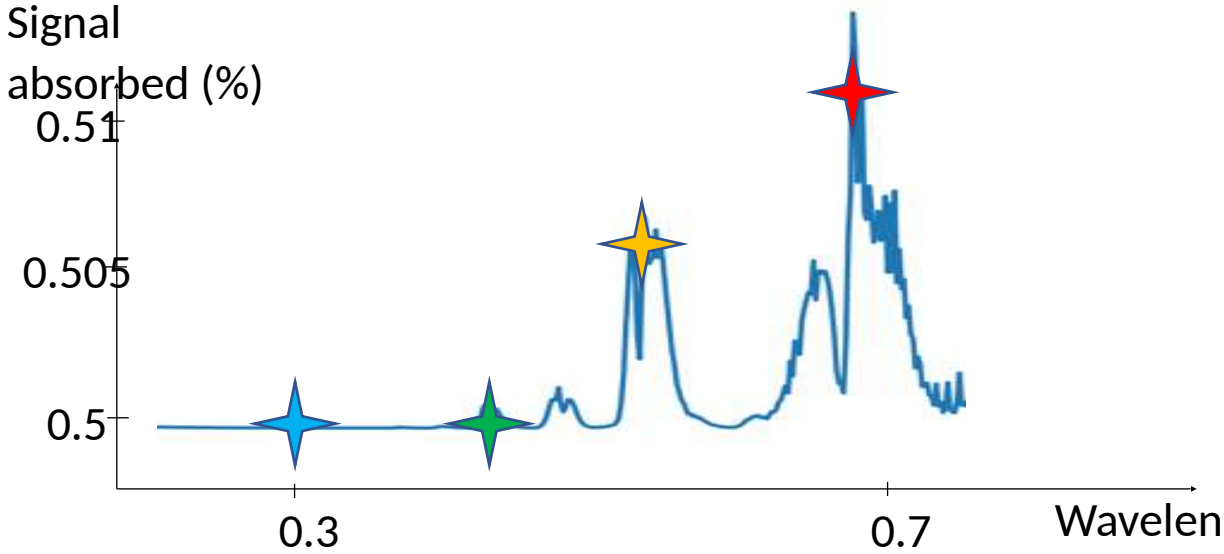
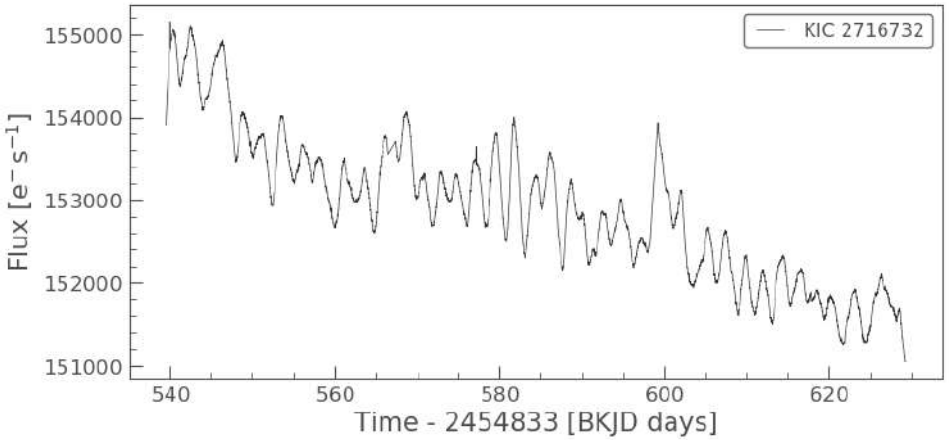


What's the problem?

- Low SNR: stars are much bigger than planets
- Complex Physics: limb-darkening, phase-curves, multi-planets…
- Variable stars: Spots, flares…
- Instrument systematics: ramps, jitter, bumps…



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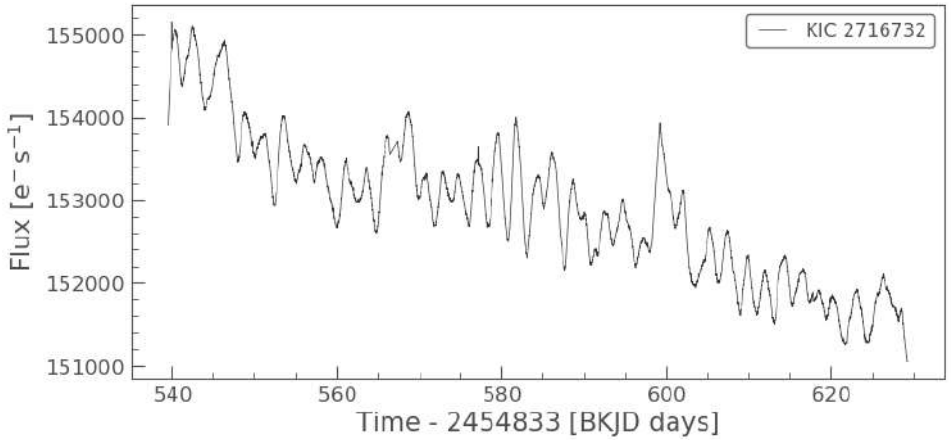
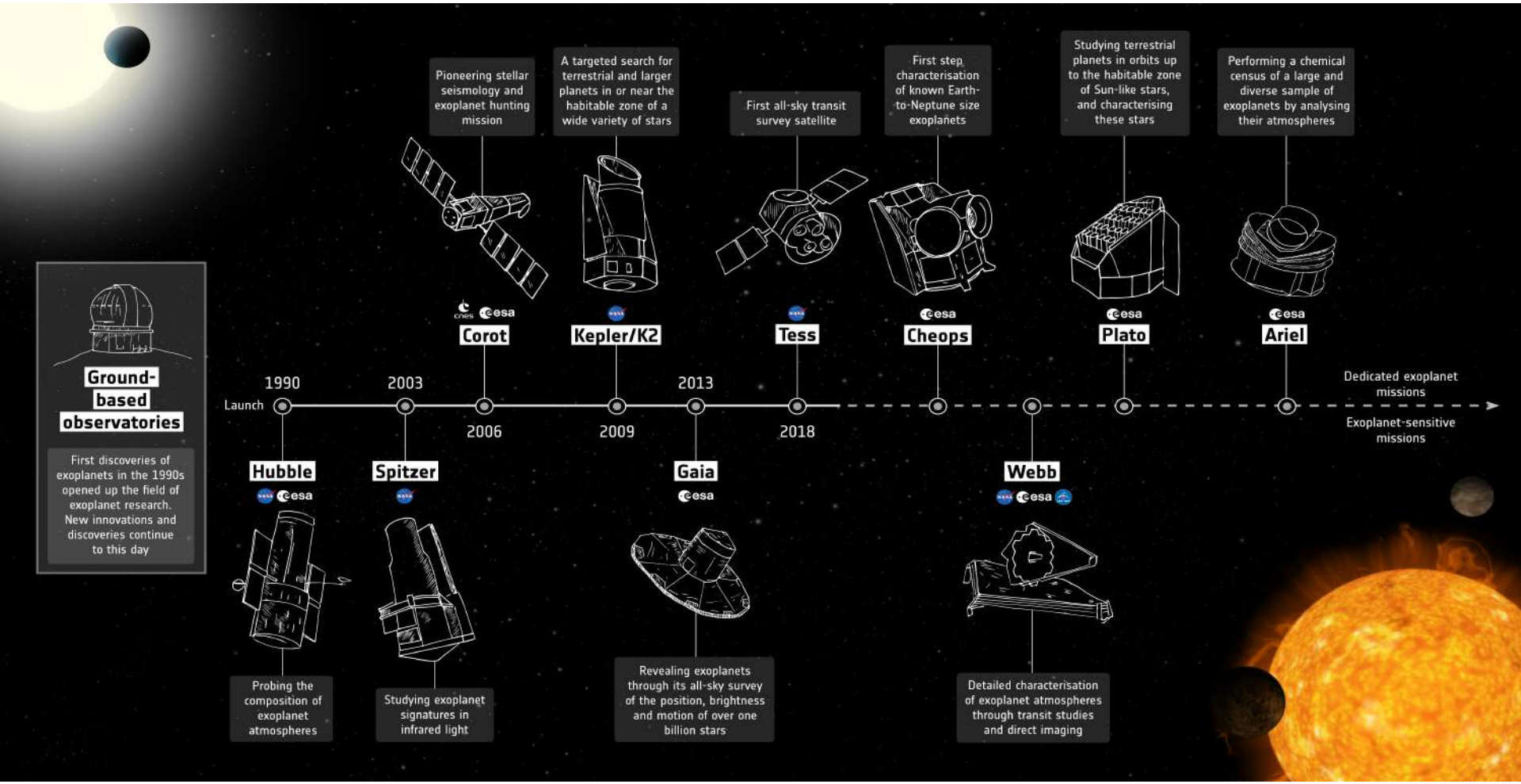


→ **Observed Light Curves are complex stochastic Time-Series**
They can't be modelled fully analytically

Transits observation



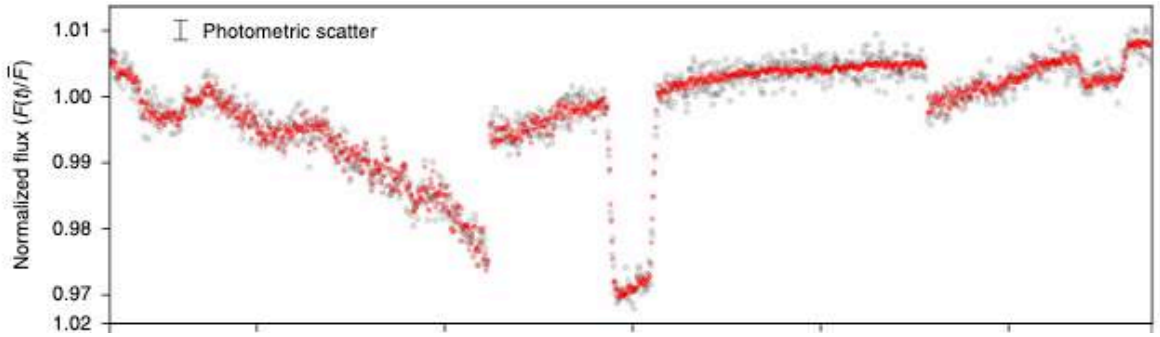
Data Volumes

- Large amount of unprocessed data

Space Missions	Data Volume [GB/day]
Kepler	1.10
Spitzer	~1-6
Hubble	3
Tess	27.21
JWST	57.5

From one transit LC…

- Precision fitting of a physics model
  - 1ary Transit, 2ary transit, phase curves, timing…



Not detrended

[Dang et al. 2018]

From one transit LC…

- Precision fitting of a physics model
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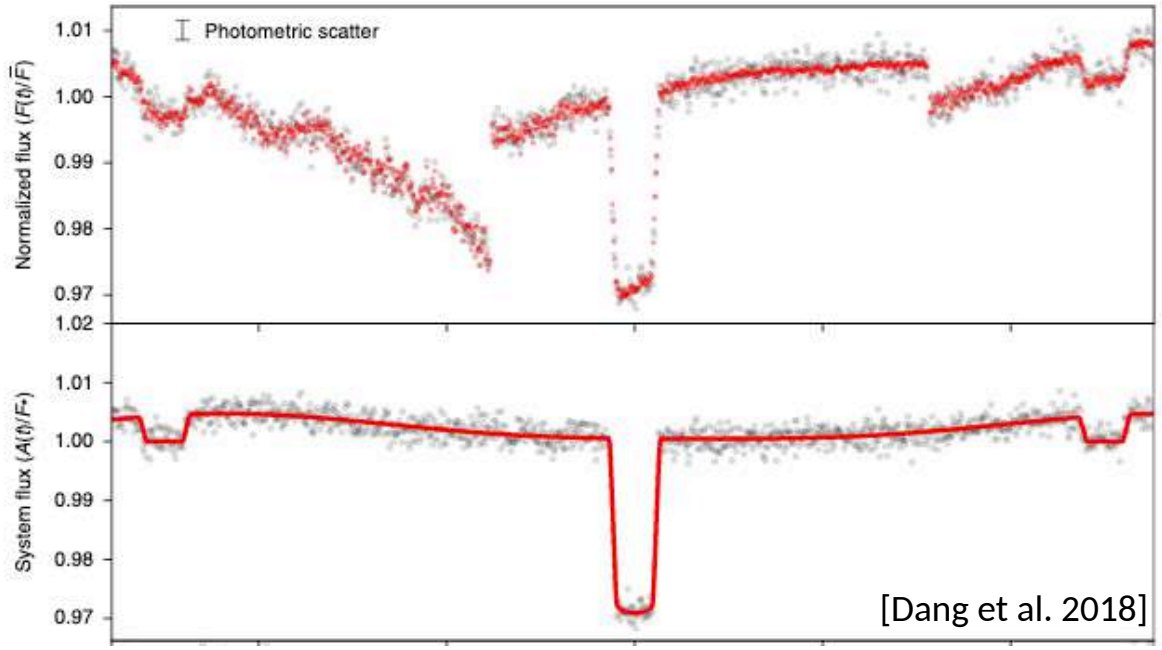
- Detrending is necessary



Not detrended

- Detrended
- Physical model fitted

…to many many LCs!

- Stellar LCs:

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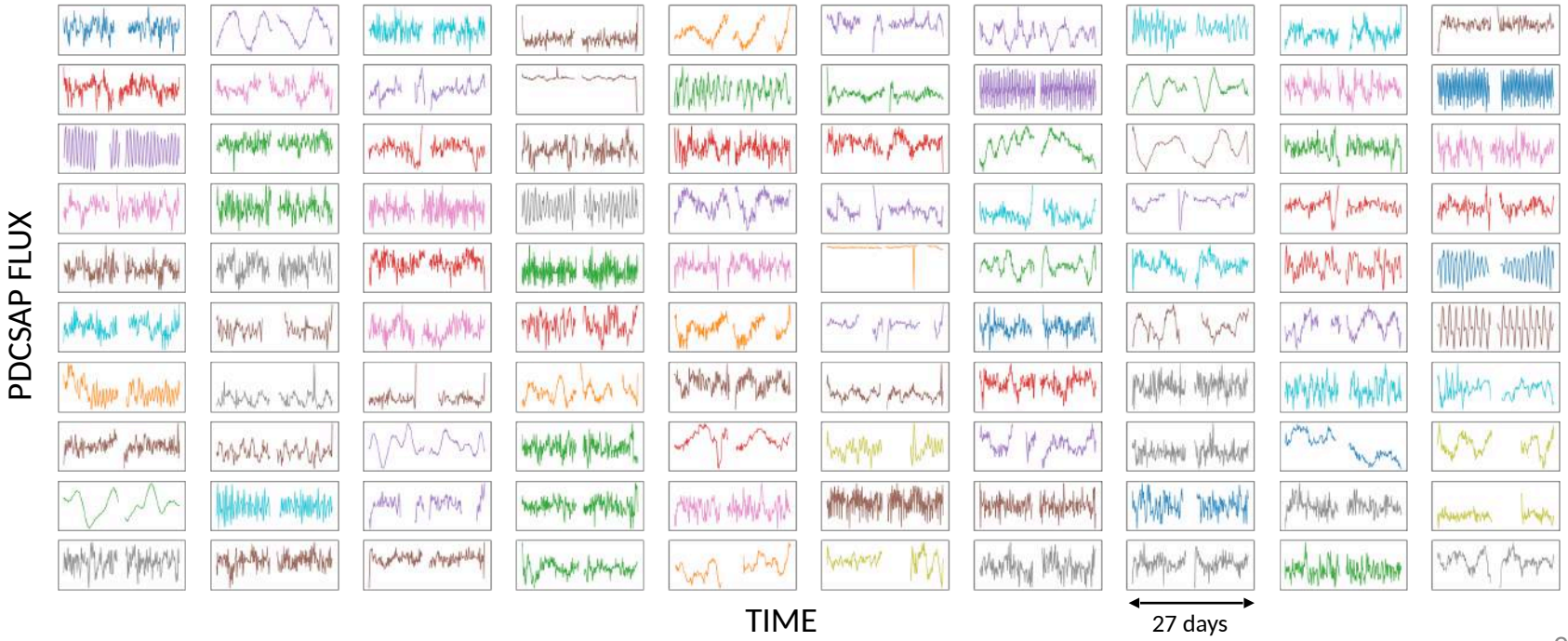
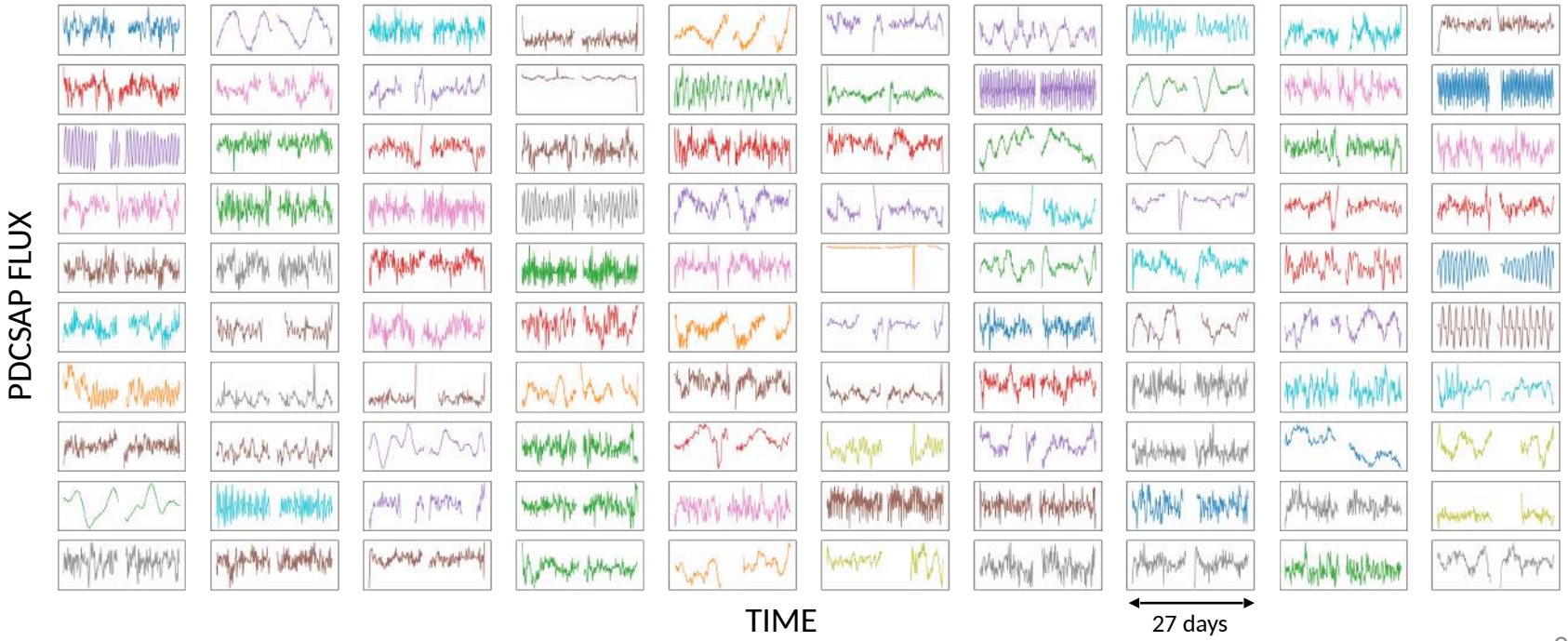


…to many many LCs!

- Stellar LCs:
  - *Clustering*



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- Stellar LCs:
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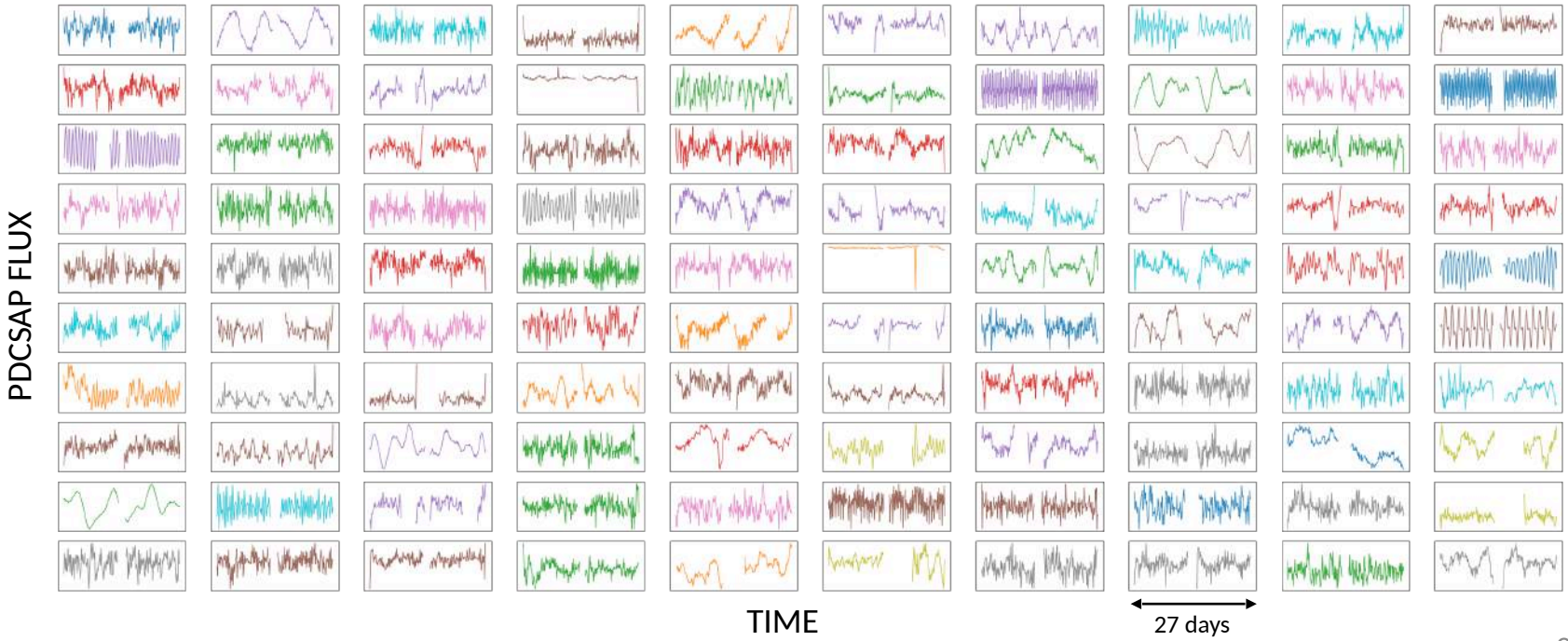

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- Stellar LCs:
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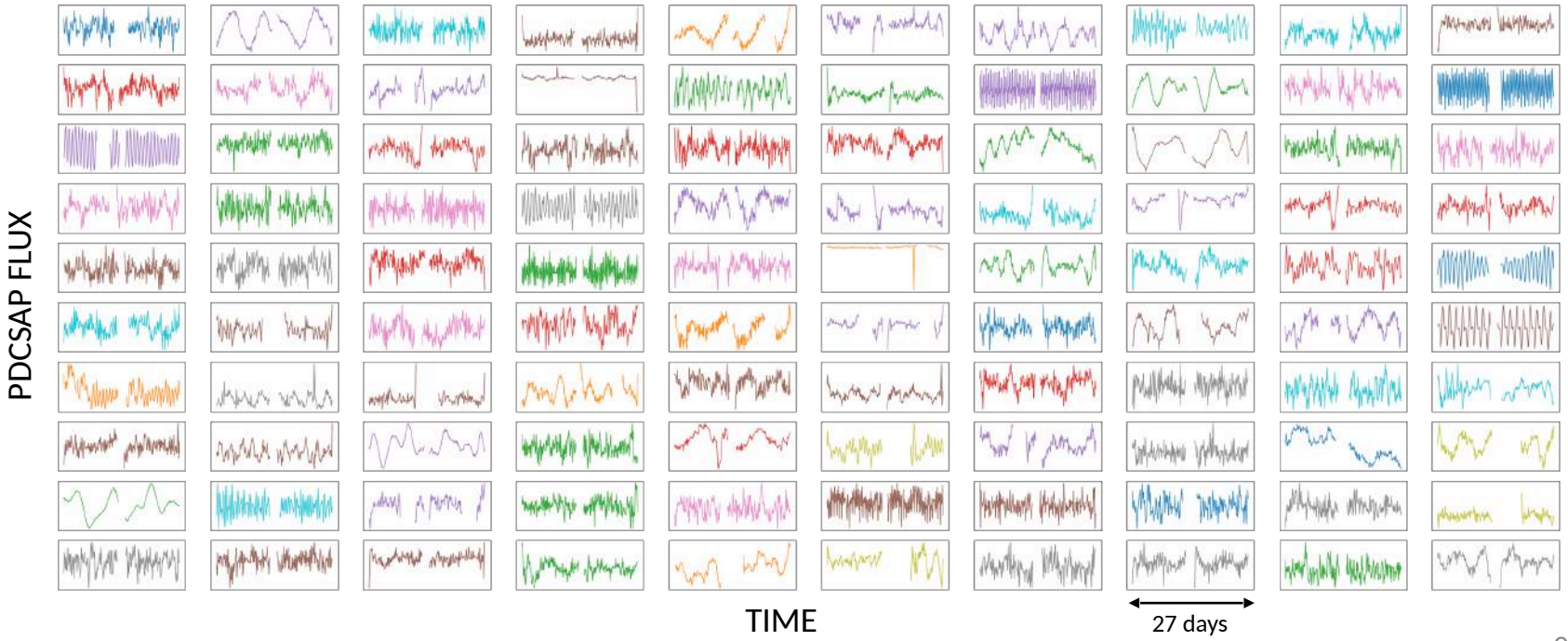
  - *Forecasting – Interpolating*



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- Stellar LCs:
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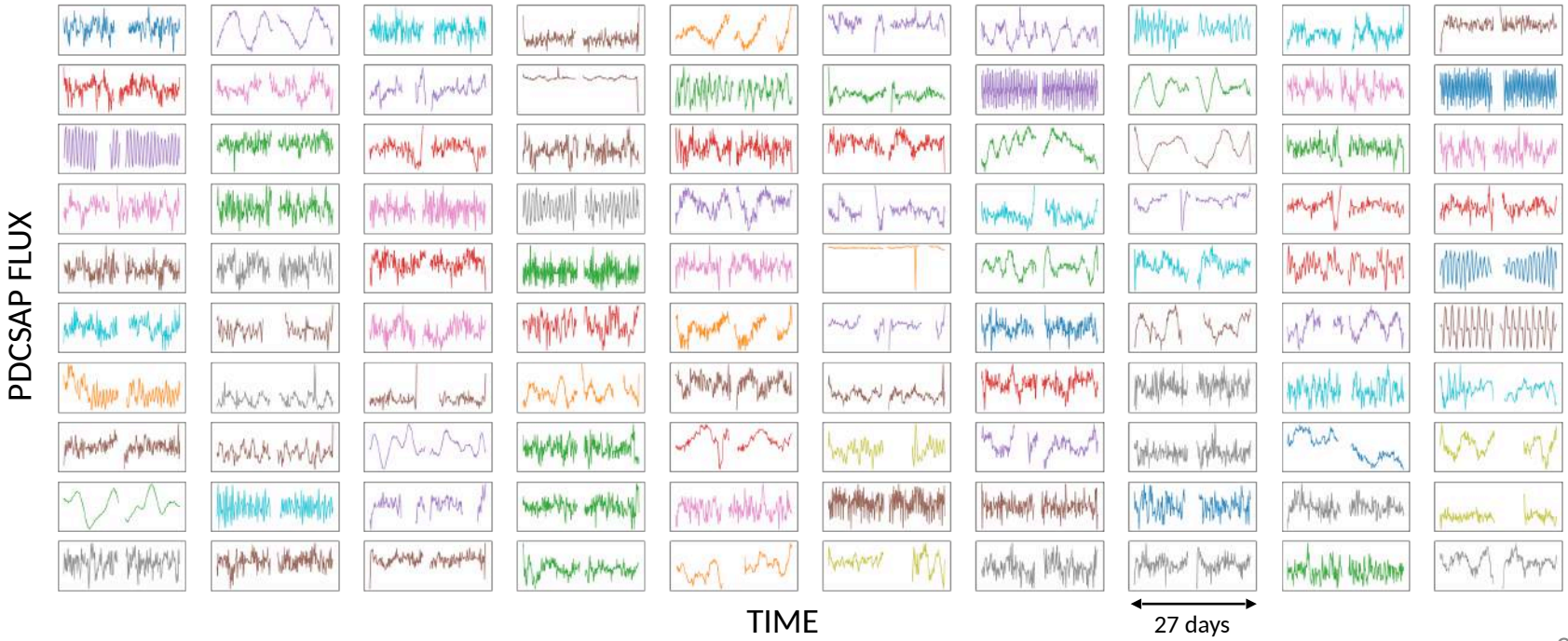

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- Stellar LCs:
  - *Clustering*
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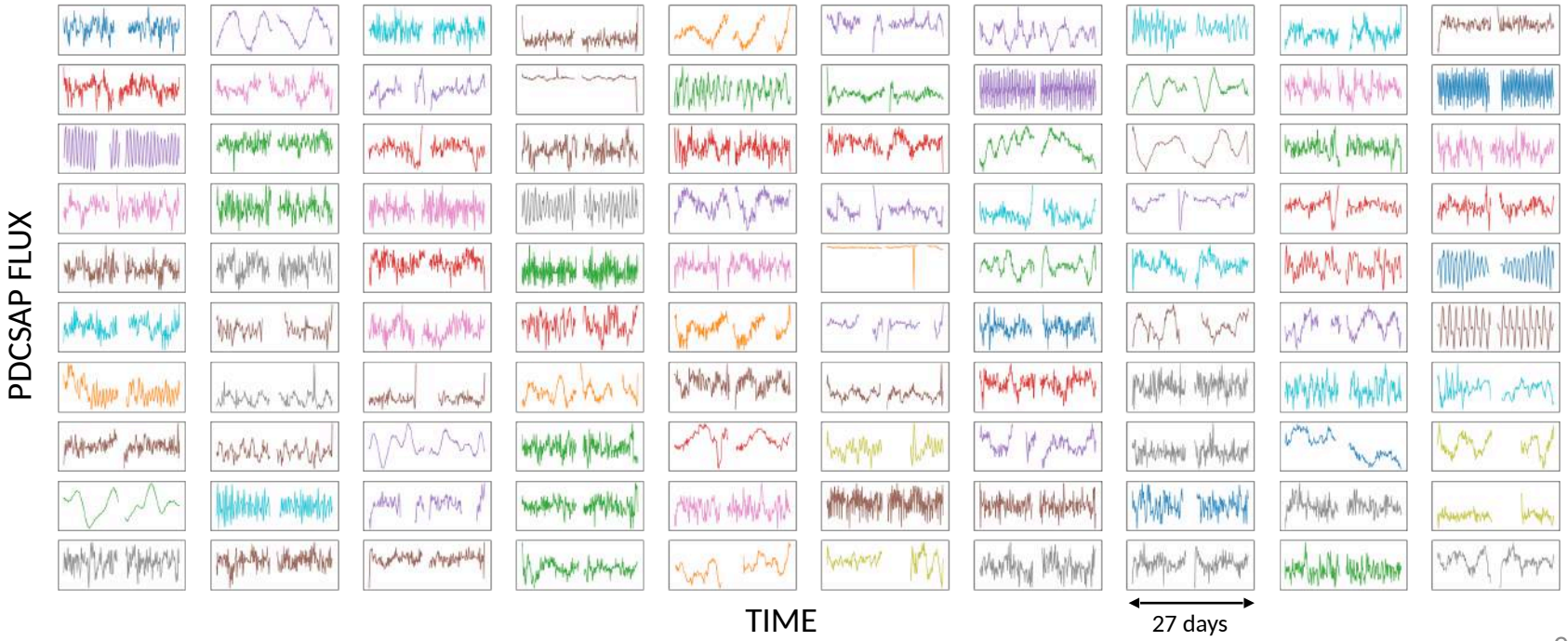
  - *Anomaly detection*
- Transits LCs *(labels avail.)*
  - *Detection*
  - *Candidate vetting*

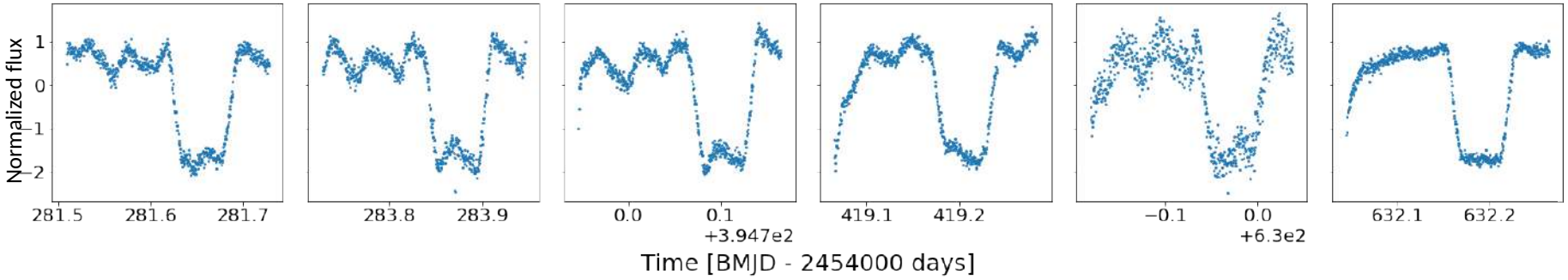


Detrending (a few) Spitzer Light Curves

The problem

Data:

- 6 observations of HD 189733 b
- Detector = IRAC 8 *μm*



Morvan et al. 2020

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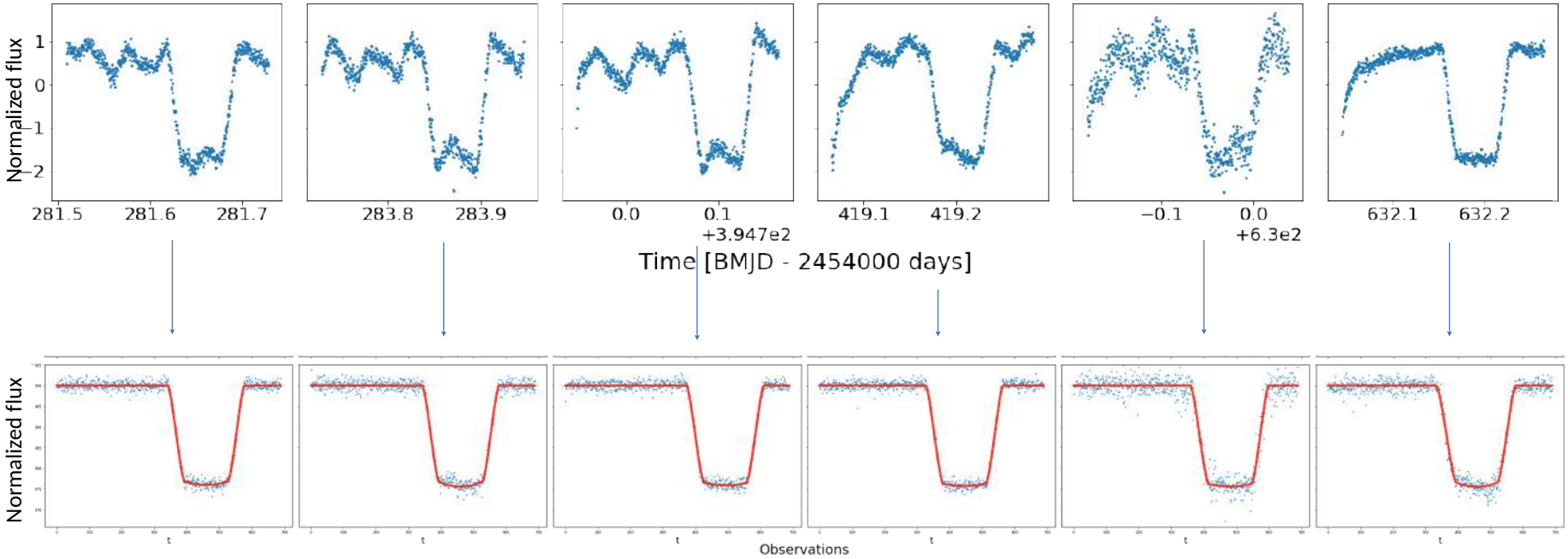

Physical model = Transit(R_P/R_S, a/R_S, P, i …)

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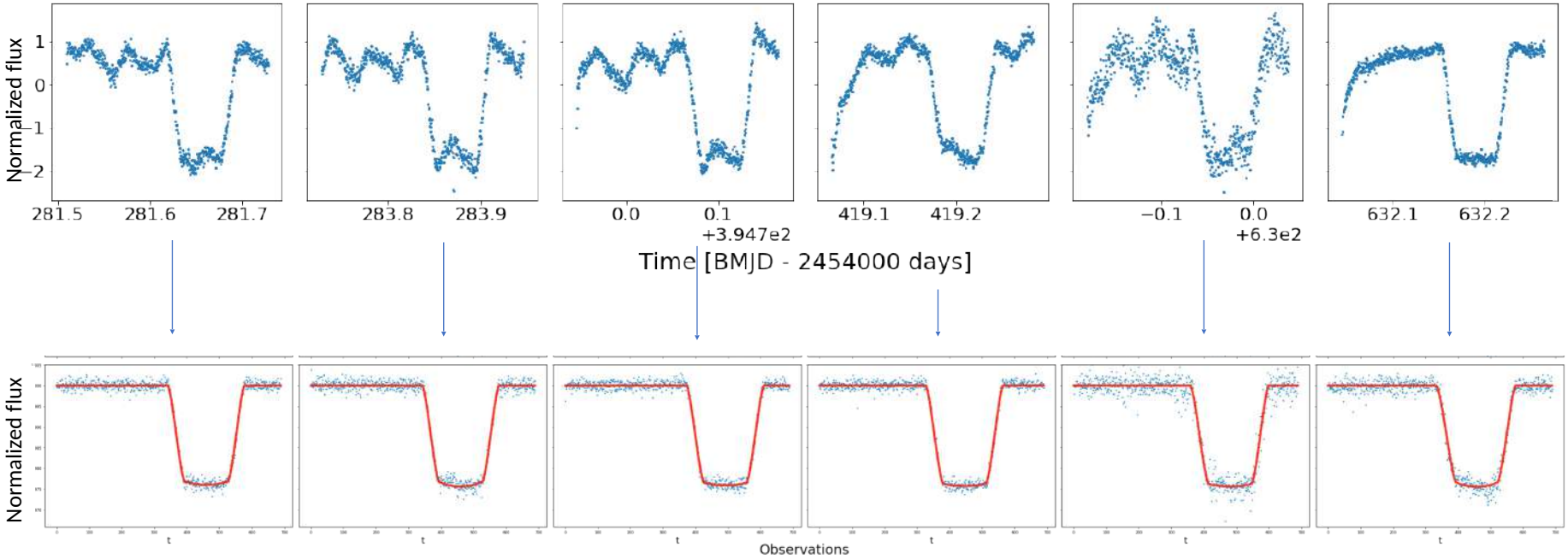

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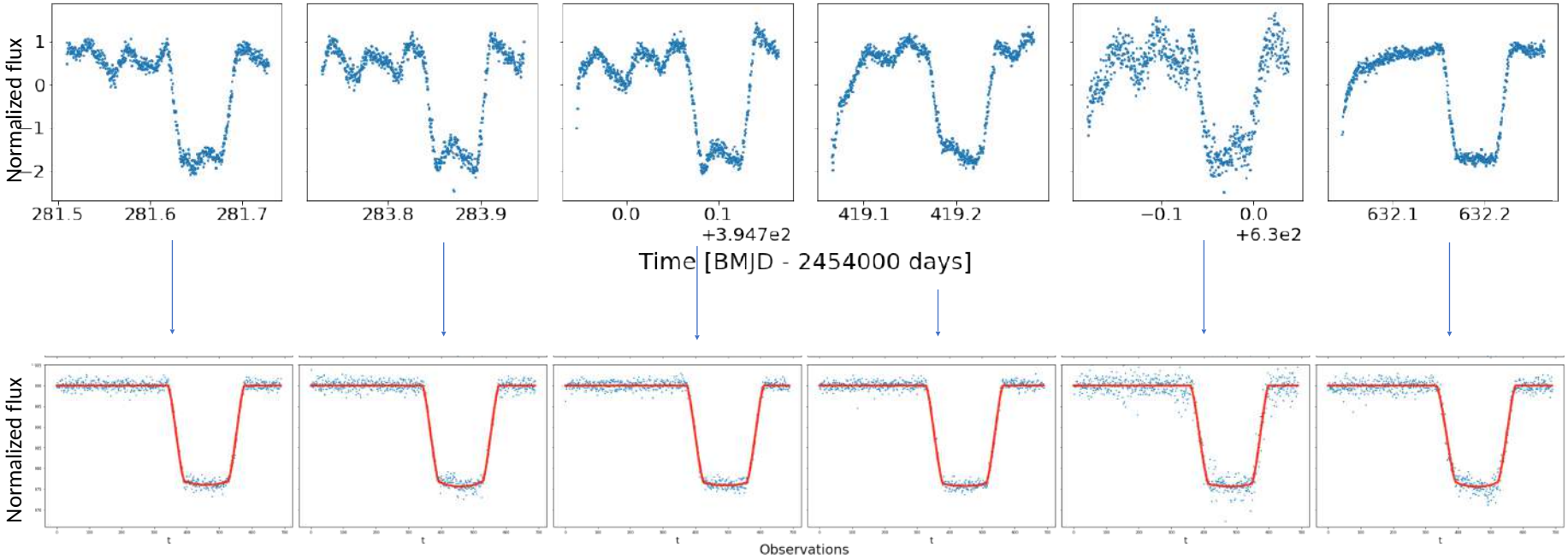

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Regression Problem.

Often decomposed in: Detrending + Fitting

Existing works: *parametric*, *PLDs*, *ICA*, *GPs*…

Anything more automatic and generalizable?

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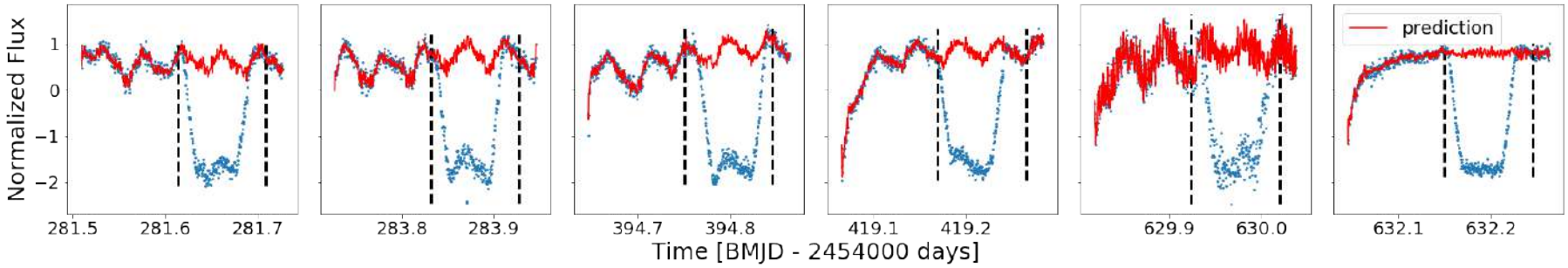
Our approach: interpolation



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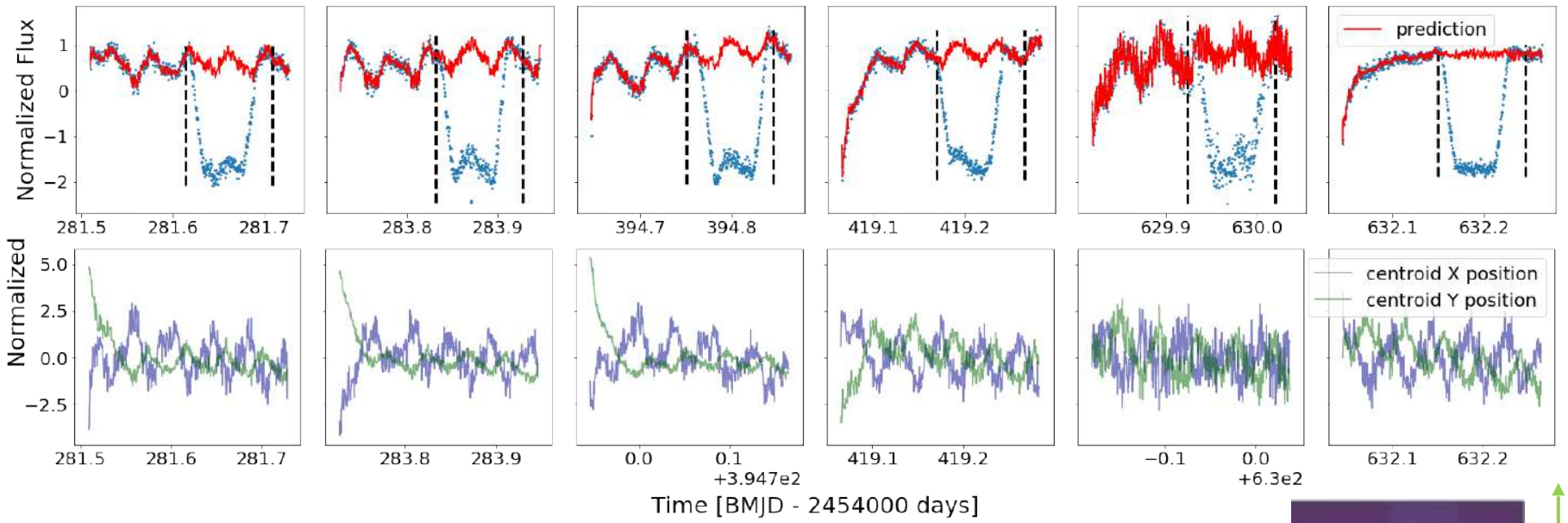

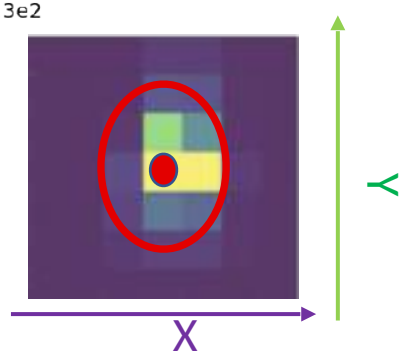

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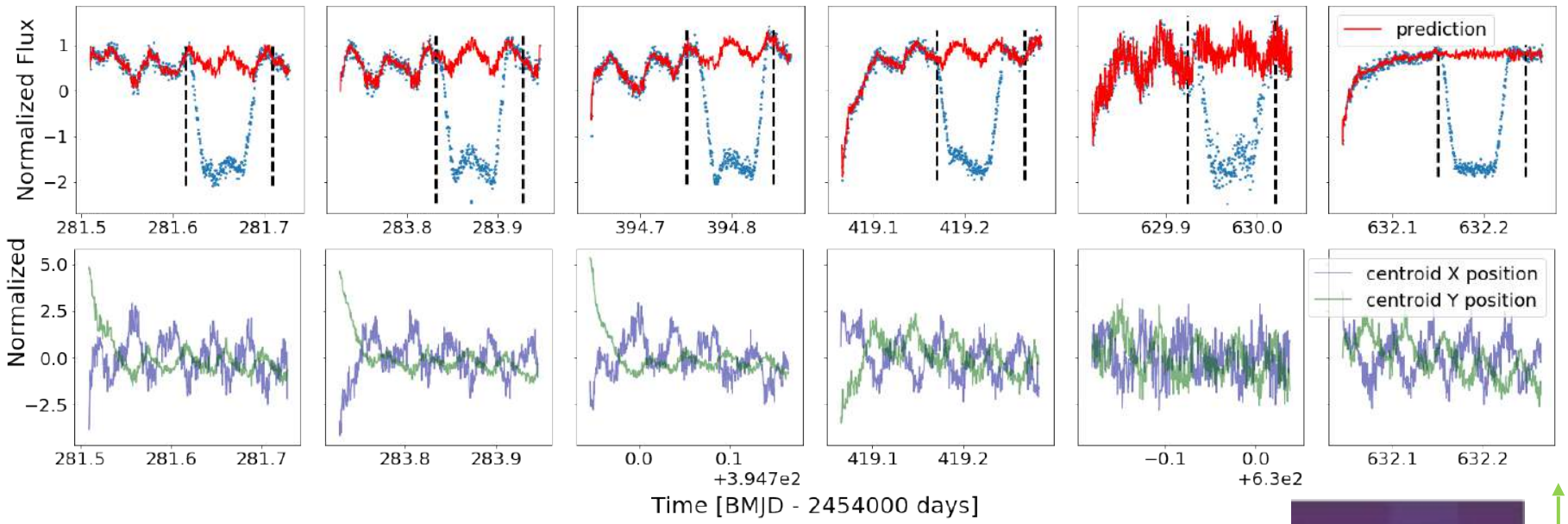
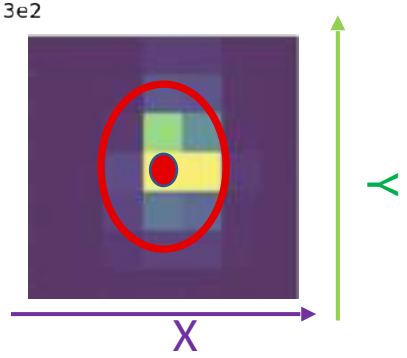


Idea:

- Use a RNN to learn the temporal dependency in the LC
  - Note: it can also learn correlation with centroids
- Train the RNN at each epoch to:
  - forecast the next step on the out-of-transit
  - Still predict on transit range: input=previous prediction, no loss computed



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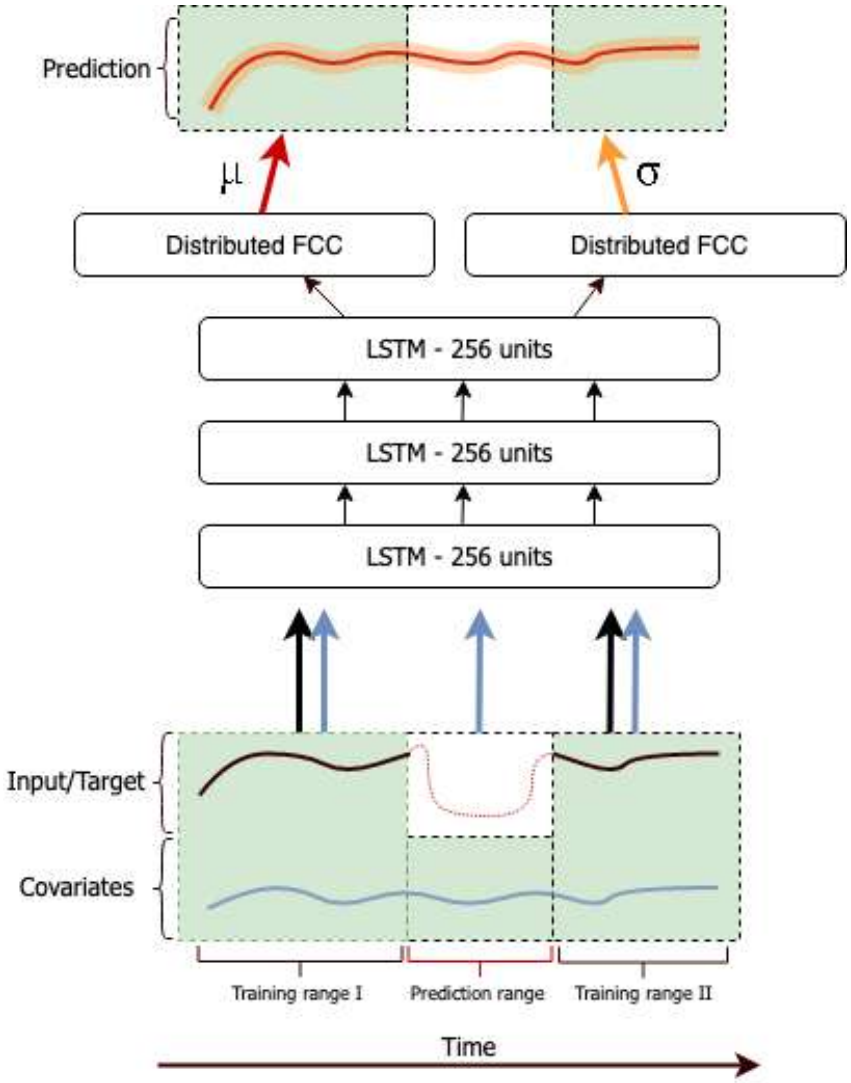
The architecture



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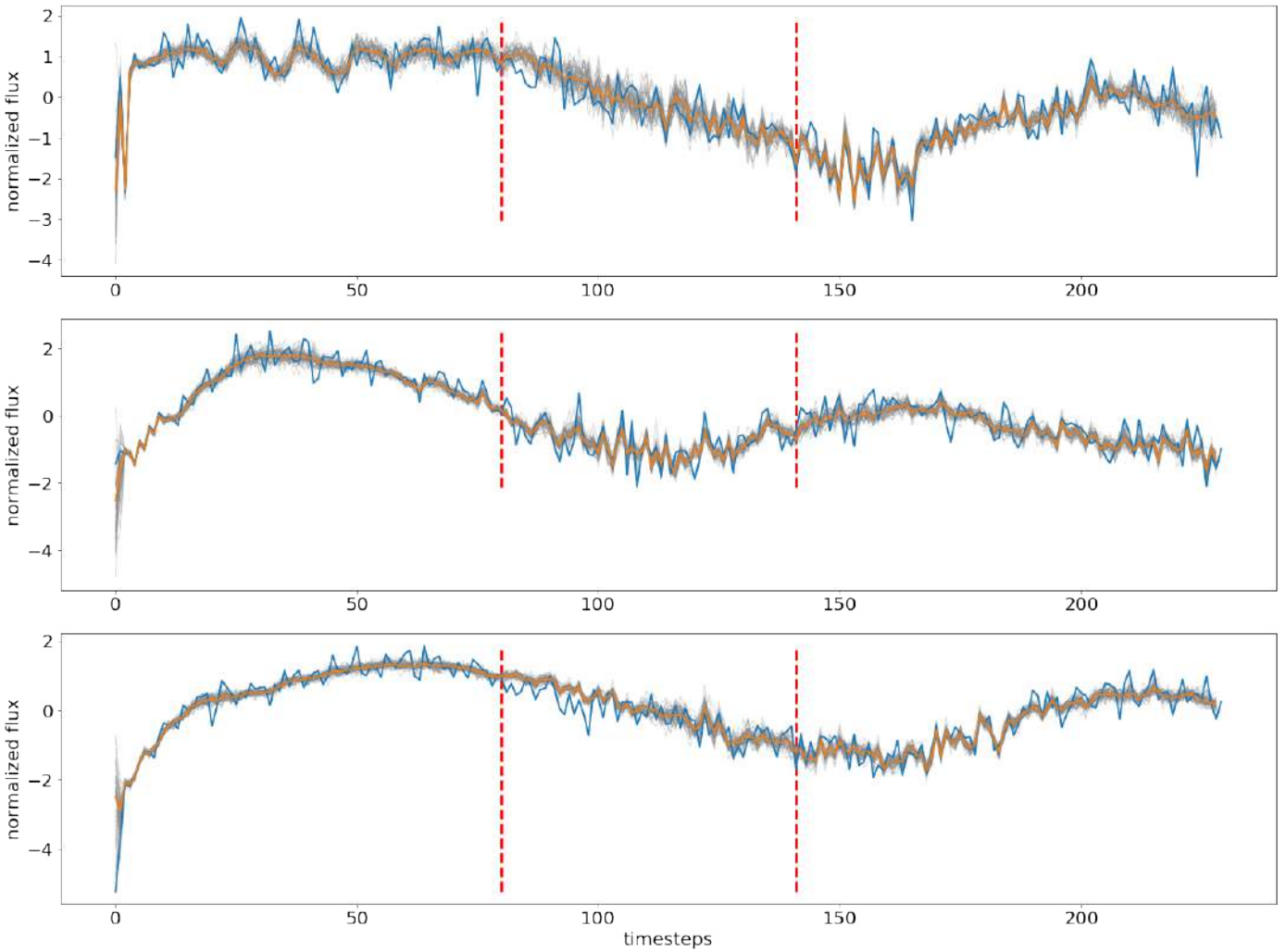
Model's validation



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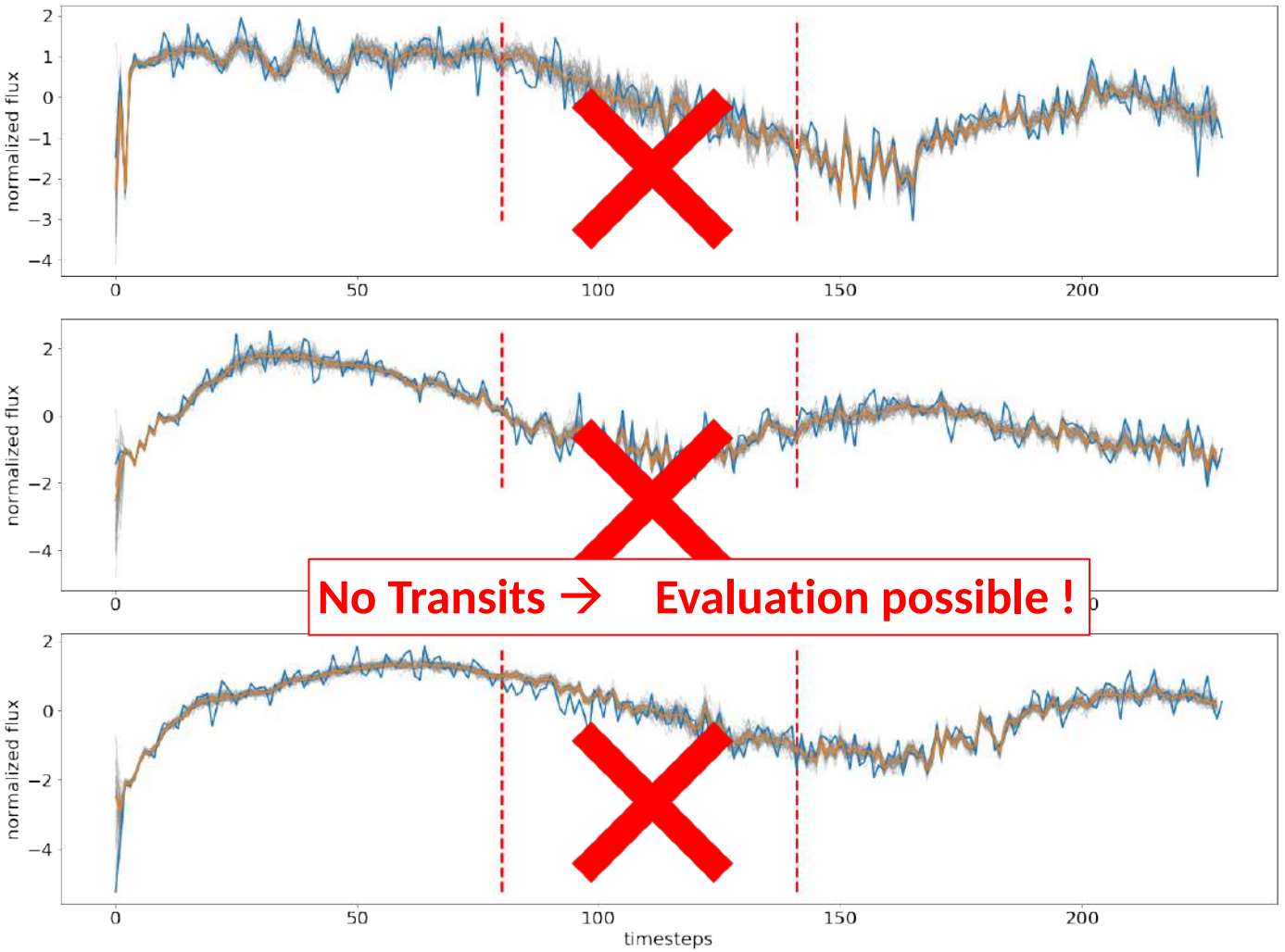

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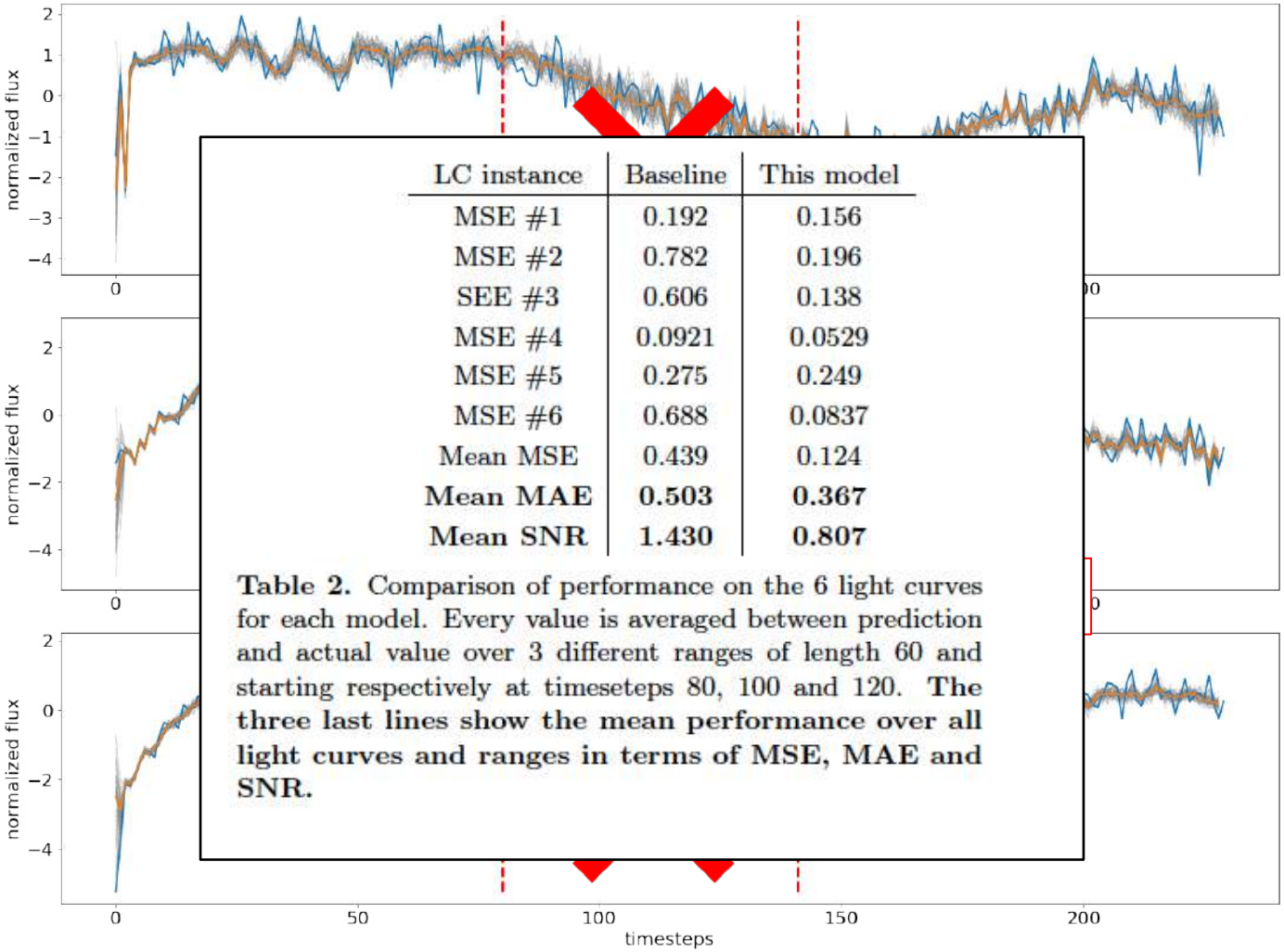

LC instance	Baseline	This model
MSE #1	0.192	0.156
MSE #2	0.782	0.196
SEE #3	0.606	0.138
MSE #4	0.0921	0.0529
MSE #5	0.275	0.249
MSE #6	0.688	0.0837
Mean MSE	0.439	0.124
Mean MAE	**0.503**	**0.367**
Mean SNR	**1.430**	**0.807**

Table 2. Comparison of performance on the 6 light curves for each model. Every value is averaged between prediction and actual value over 3 different ranges of length 60 and starting respectively at timeseteps 80, 100 and 120. **The three last lines show the mean performance over all light curves and ranges in terms of MSE, MAE and SNR.**

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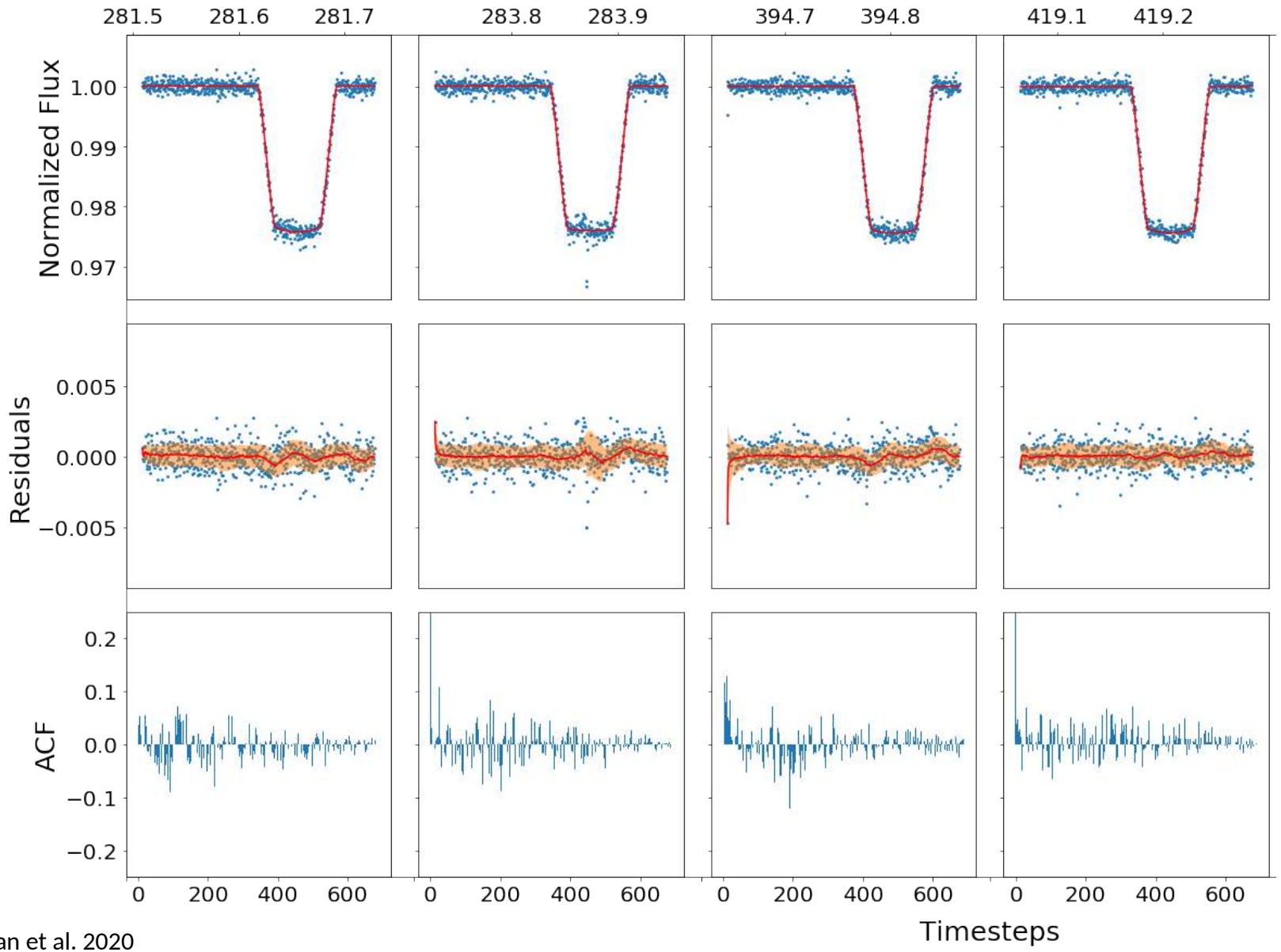
Prediction + Transit Fit



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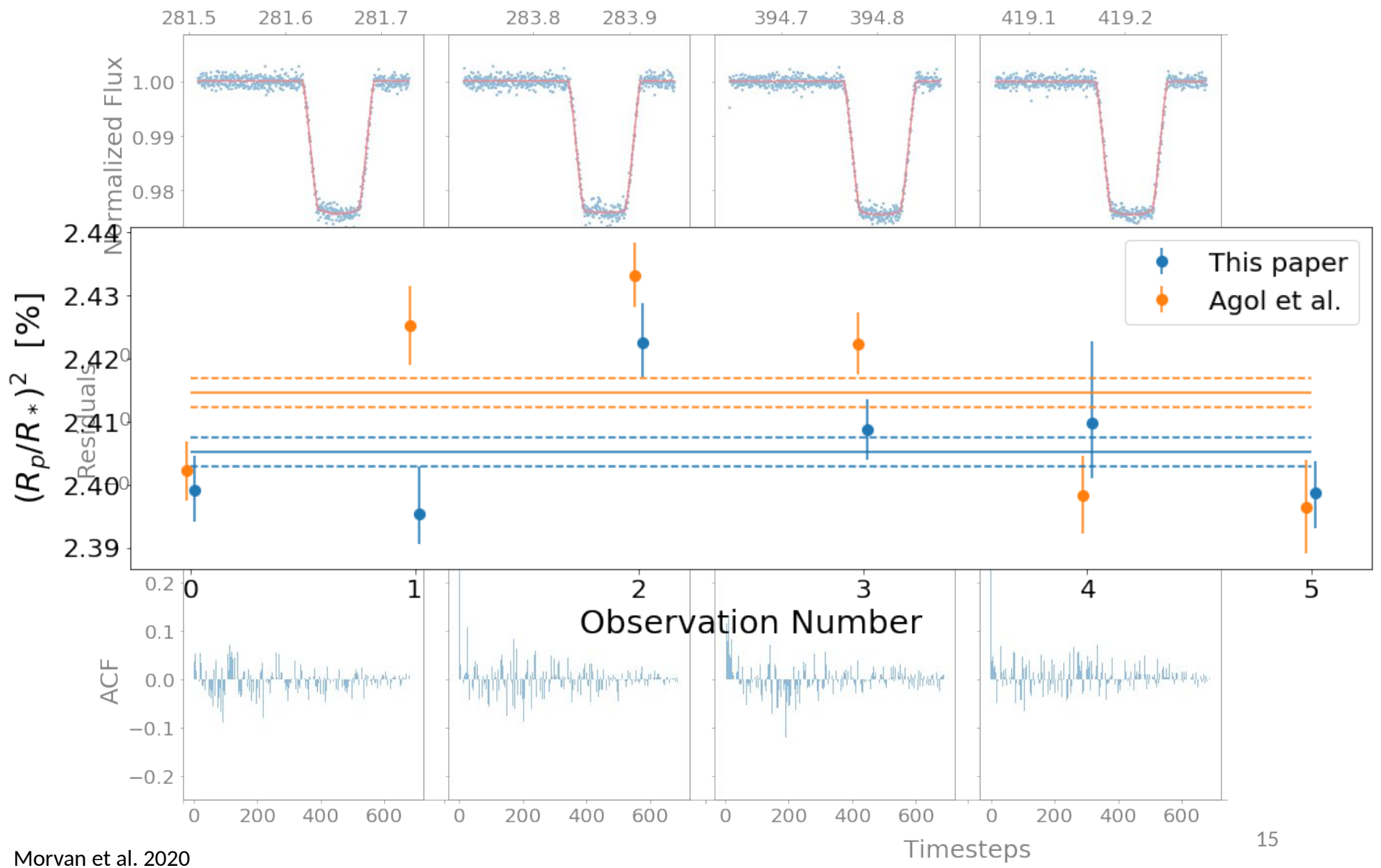

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Conclusion

- Many exoplanets
- Many many light curves
- Work on Spitzer
  - → LSTM models time dependencies in individual LCs
  - → Useful for **detrending LCs**.
- Preliminary work on TESS
  - →hopes for a **global LC model**
- Towards a global, automatic detrending pipeline?
- Would be great for JWST, Cheops, Plato, Ariel…

SOFTWARE

DeepARTransit: Morvan, M. 2019, DeepARTransit: A library for interpolating and detrending transit light curves, 1.0.0, Zenodo, doi: 190091225
PyLightcurve: https://github.com/ucl-exoplanets/pylightcurve/
Lightkurve: This research made use of Lightkurve, a Python package for Kepler and TESS data analysis (Lightkurve Collaboration, 2018).

REFERENCES

Agol E, Cowan NB, Knutson HA, Deming D, Steffen JH, et al. 2010. *The Astrophysical Journal*. 721(2):1861–77

Cassan A, Kubas D, Beaulieu J-P, Dominik M, Horne K, et al. 2012. *Nature*. 481(7380):167–69

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Thank you

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