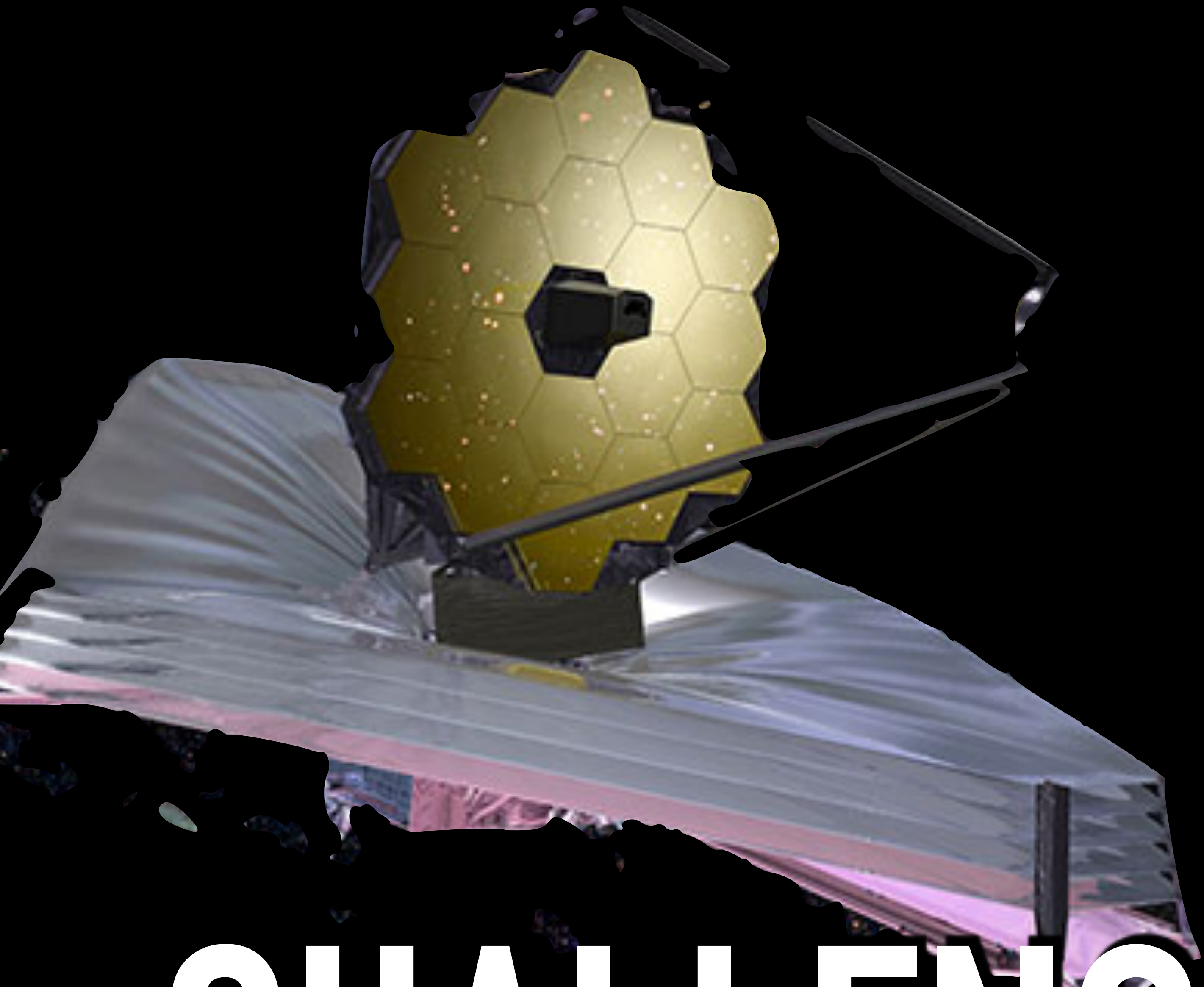


Summer 2021
ERS PRE-LAUNCH
DATA HACKATHON

CHALLENGES IN EXOPLANET TIMESERIES OBSERVATIONS

Dr HANNAH R. WAKEFORD

Lecturer in Astrophysics

University of Bristol

University of Bristol
School of Physics

exocast
the exoplanet podcast

STARGATE
Collaboration

THE GOAL OF UNDERSTANDING THE ATMOSPHERES OF EXOPLANETS

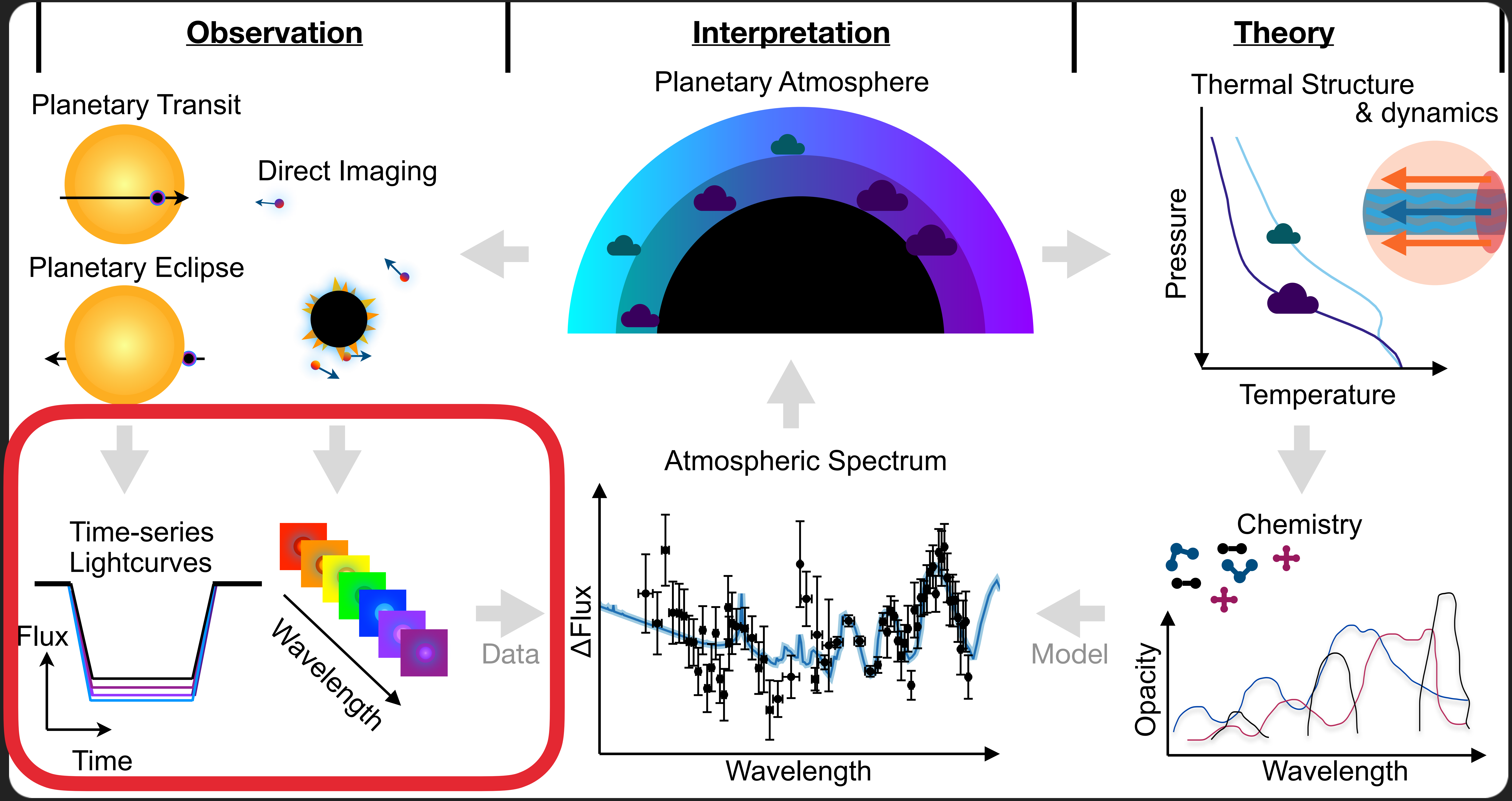
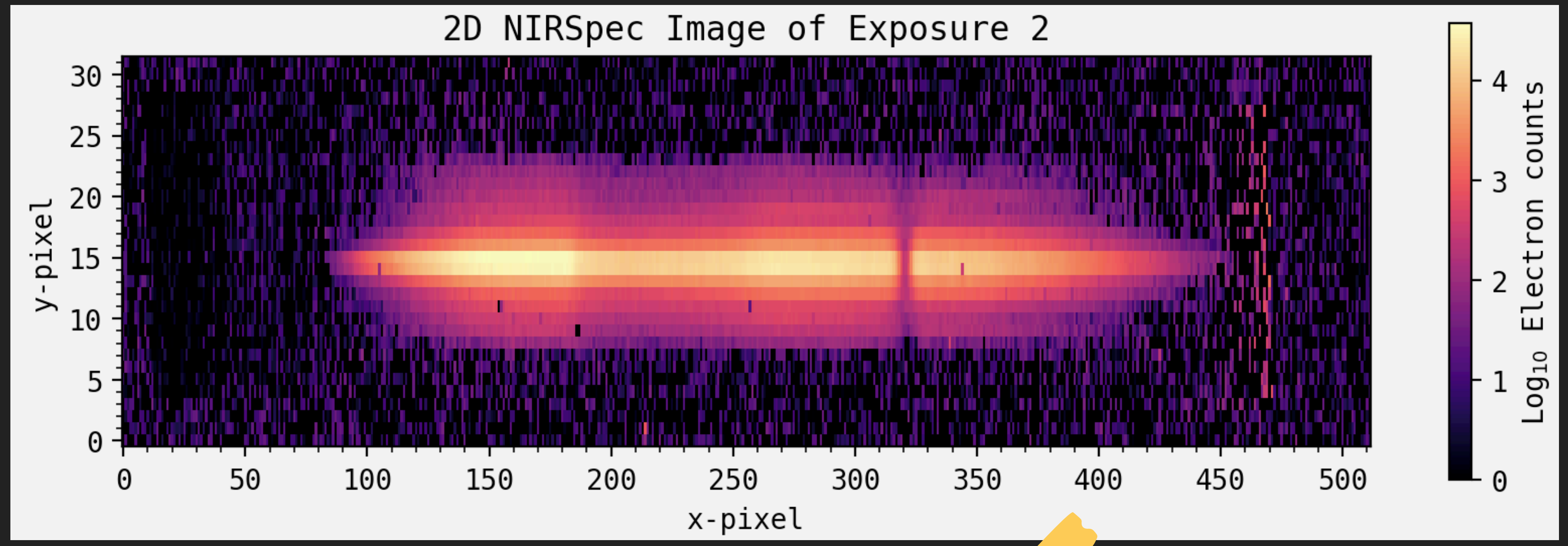
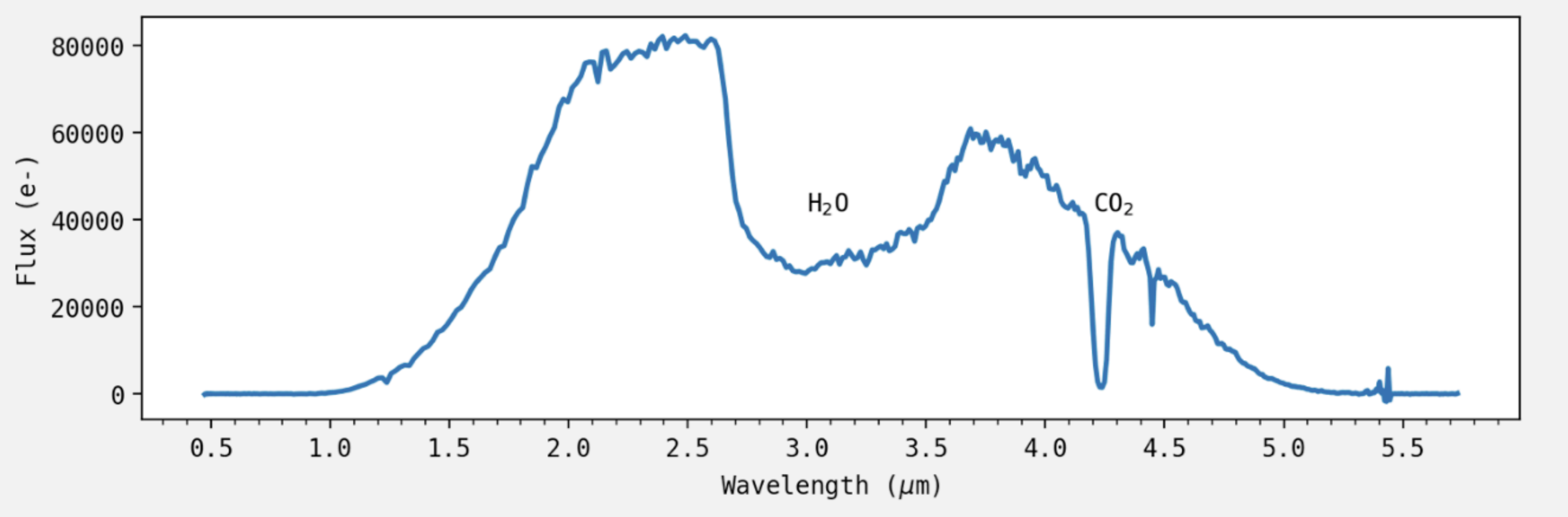


Image credit: Hannah Wakeford

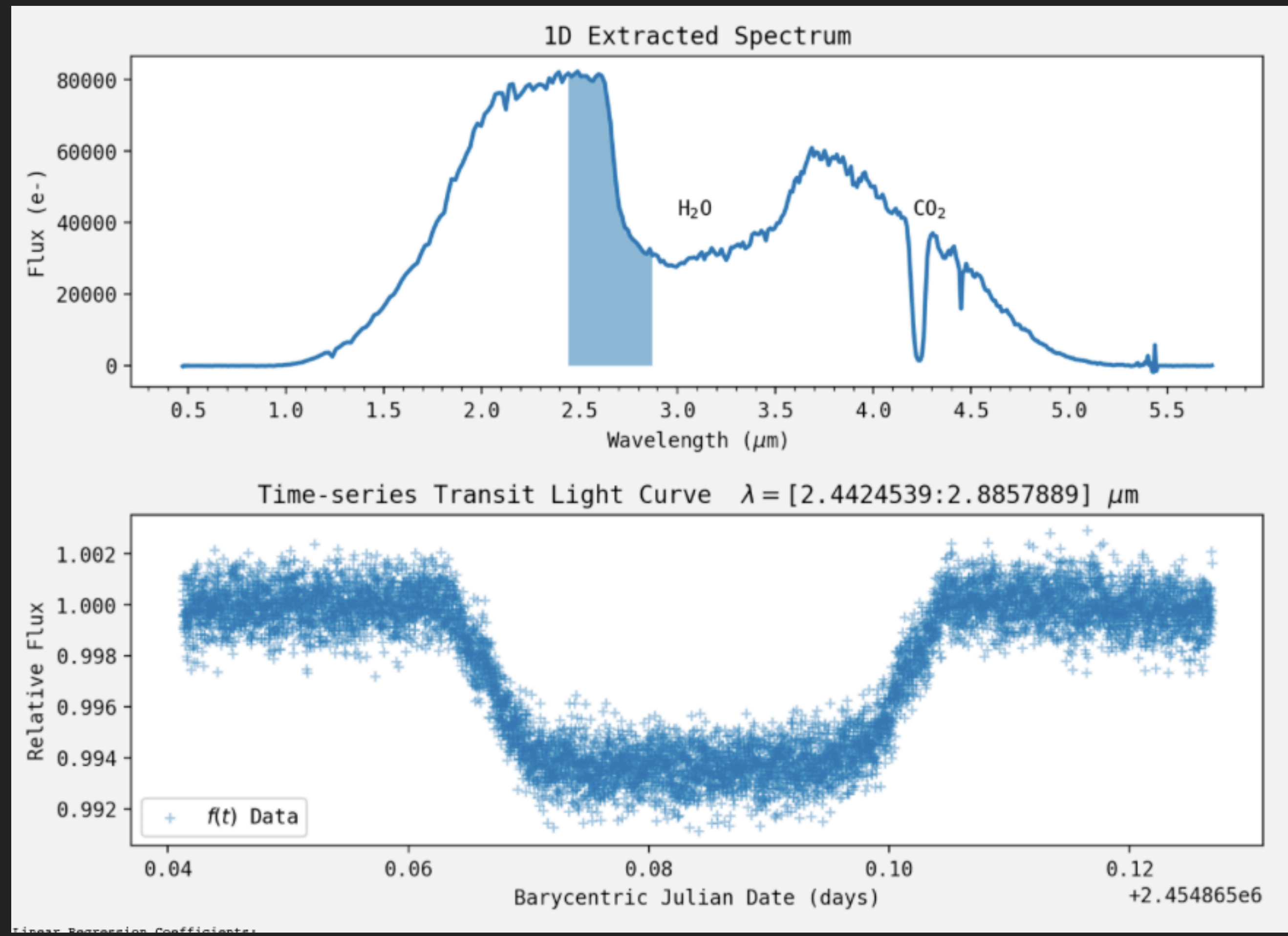
HOW TO GO FROM STELLAR TO PLANETARY SPECTRA



From 2D images to 1D stellar spectra

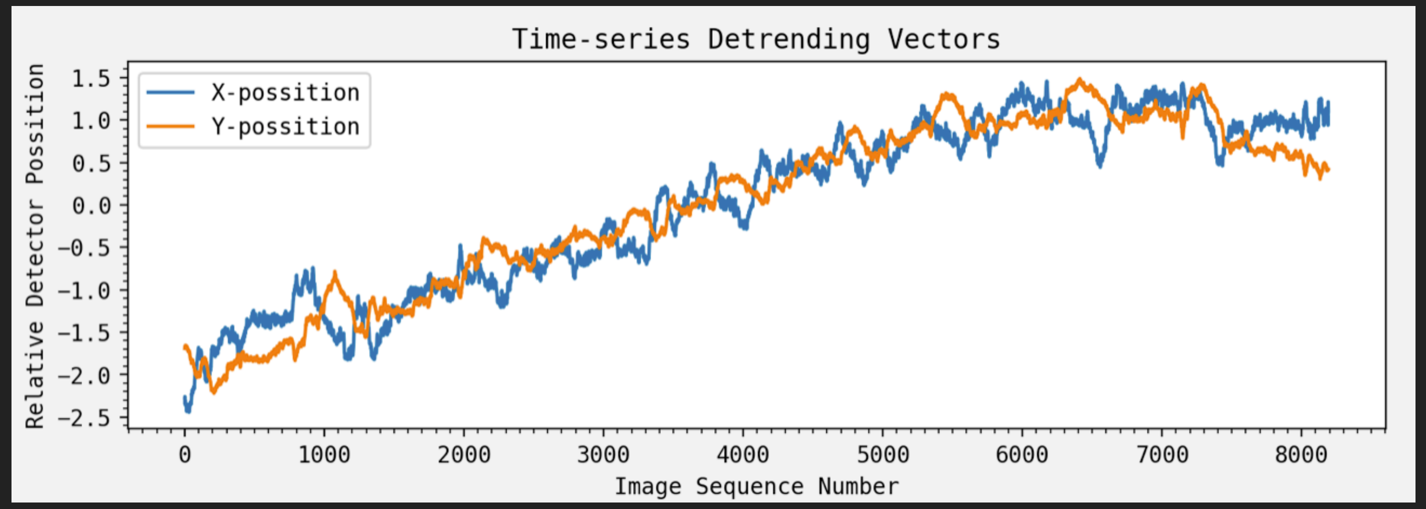


Spectroscopic light curve



+

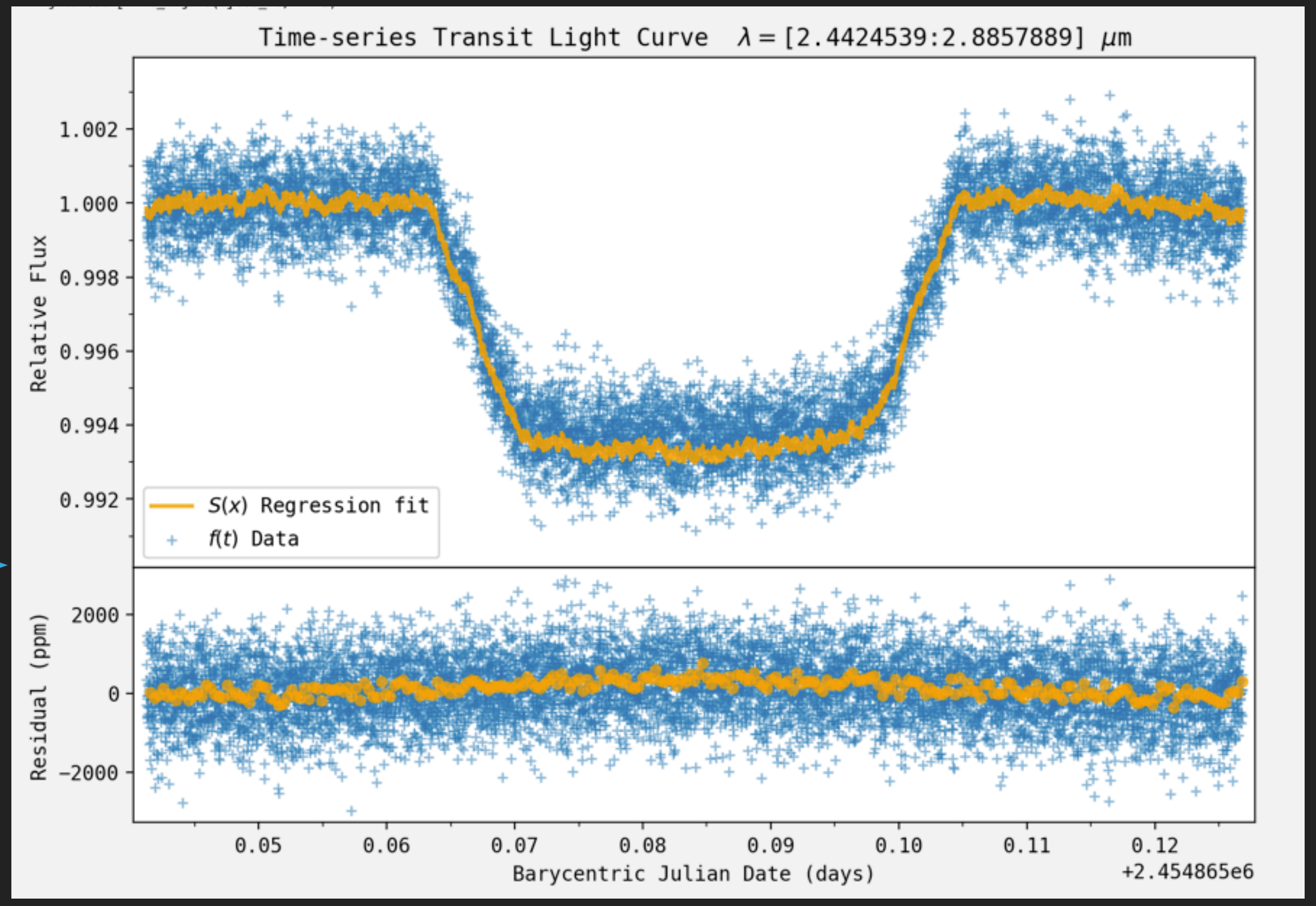
Detrending parameters



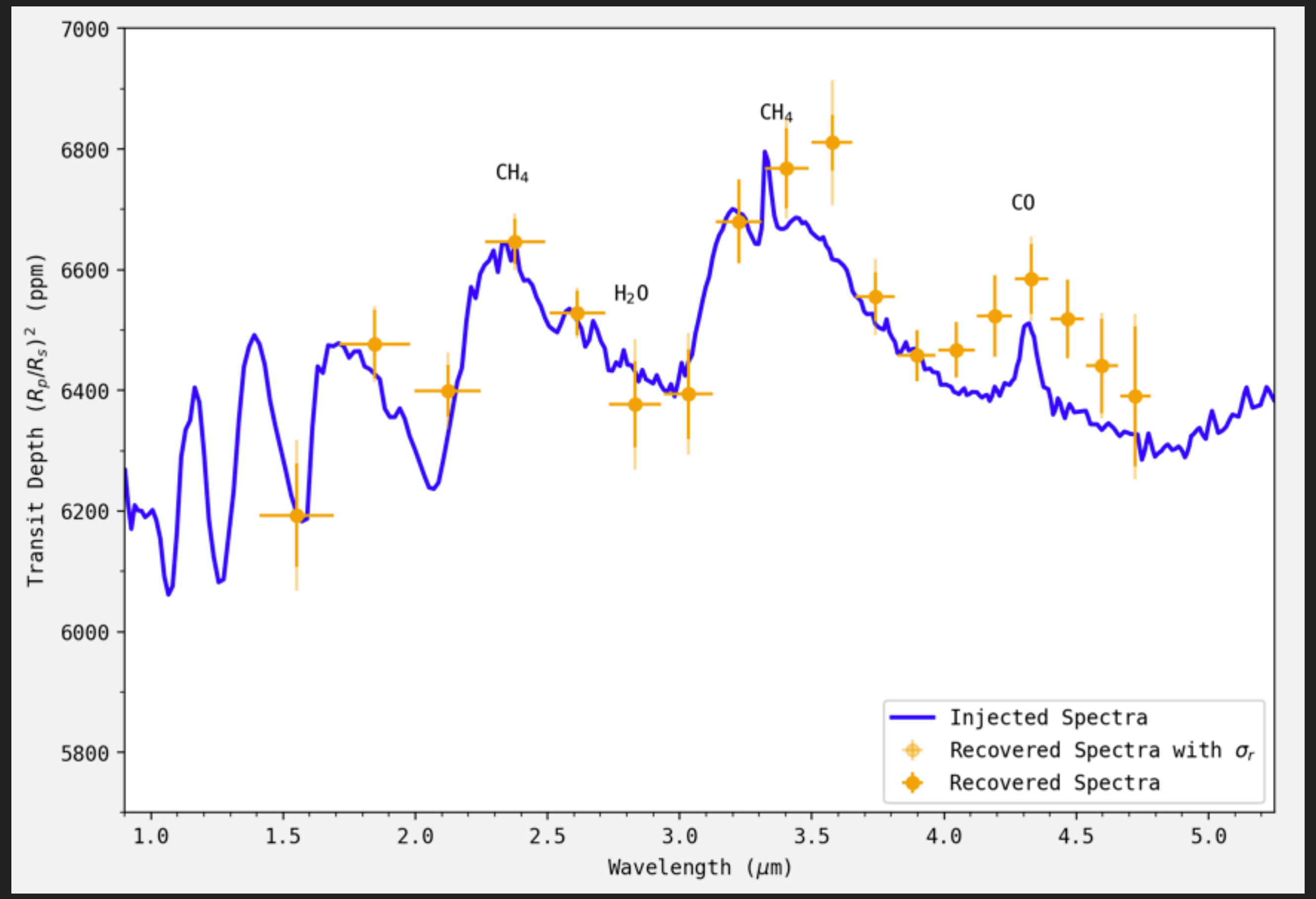
+

...

Fitted light curve



Planetary spectrum



Images from D.Sing NIRSpec reduction using ExoTiC-ISM functions - see https://spacetelescope.github.io/jdat_notebooks/notebooks/transit_spectroscopy_notebook/Exoplanet_Transmission_Spectra_JWST.html

WHAT WE USE TO MAKE OUR ATMOSPHERIC MEASUREMENTS

Many of the telescopes we use to characterize exoplanet atmospheres were not designed for it!

Hubble, *Spitzer*, and even *Webb* were not initially designed to deal with time series data at all.


They were designed for this……

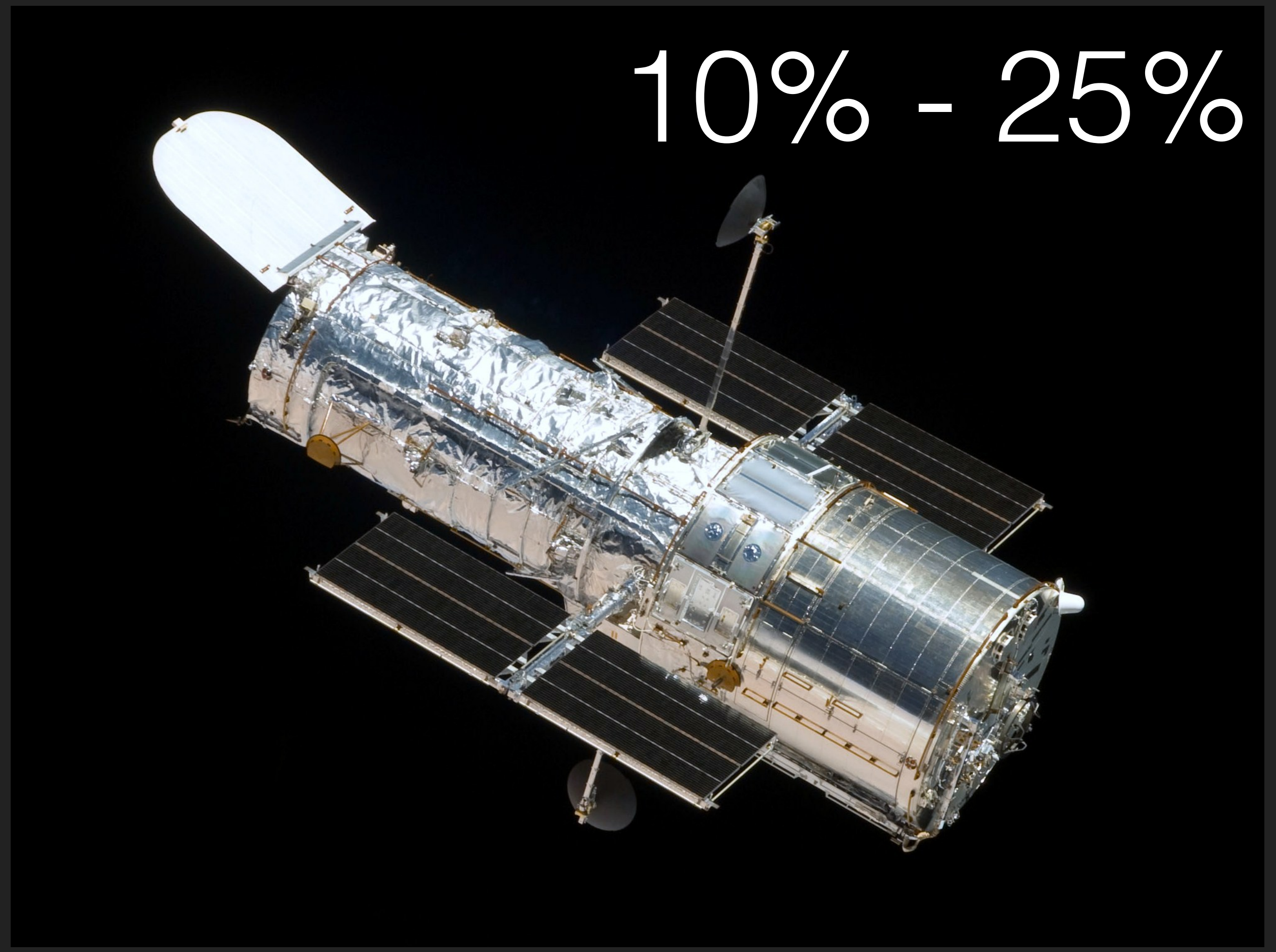
YET, EXOPLANET SCIENCE COMMAND A HUGE FRACTION OF TIME

No longer in operation

Conducted long >1000 hour observations

IR spectra and multi-band photometry before 2008

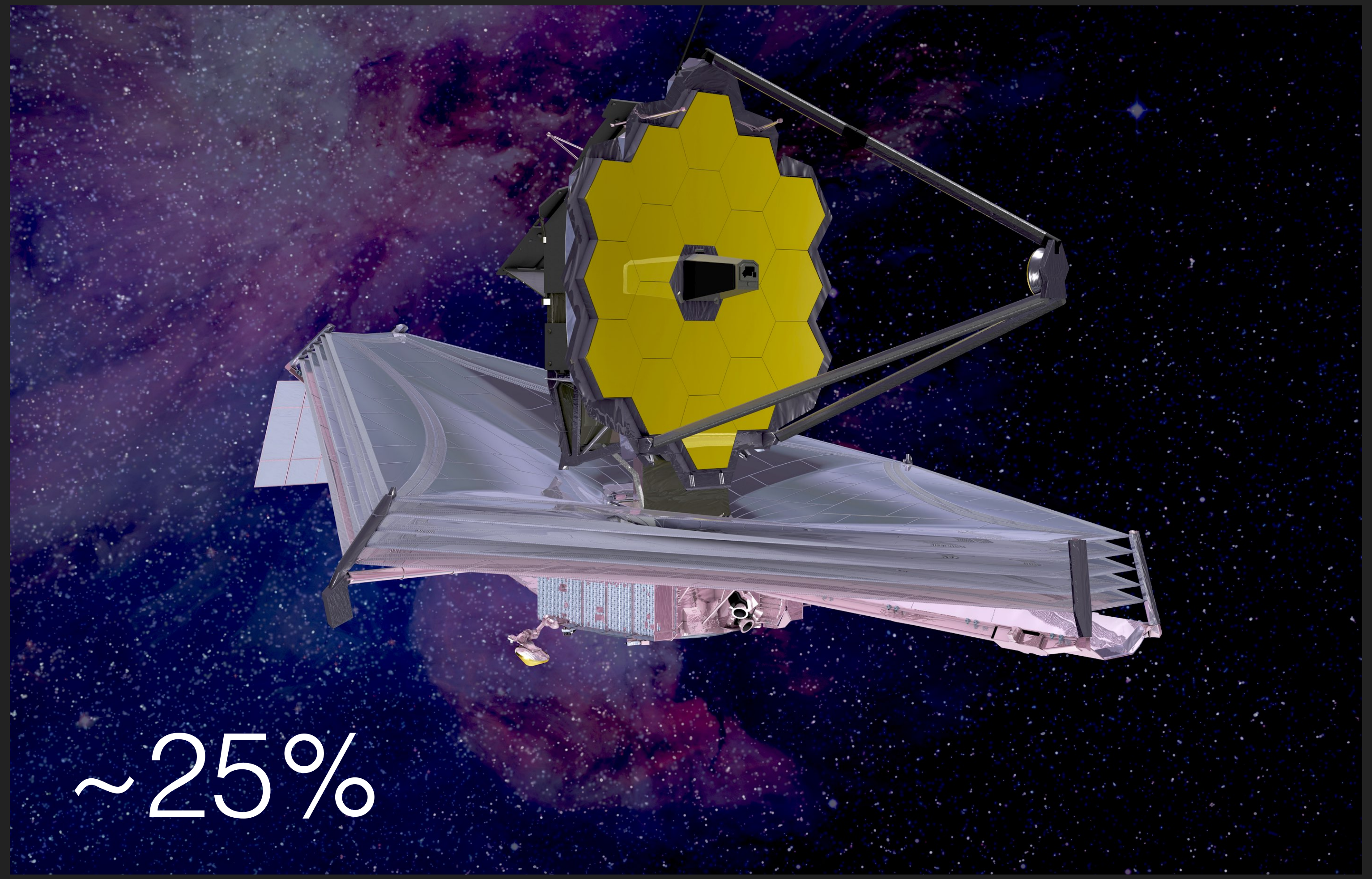
IR two-band photometry warm-Spitzer



Still conducting observations and is expected to last many more years.

UV to near-IR low res spectra with 3/4 core instruments used for exoplanets

UV - near-IR observations are vital for our interpretation of exoplanet atmospheres, especially their aerosols



Soon to be in operation

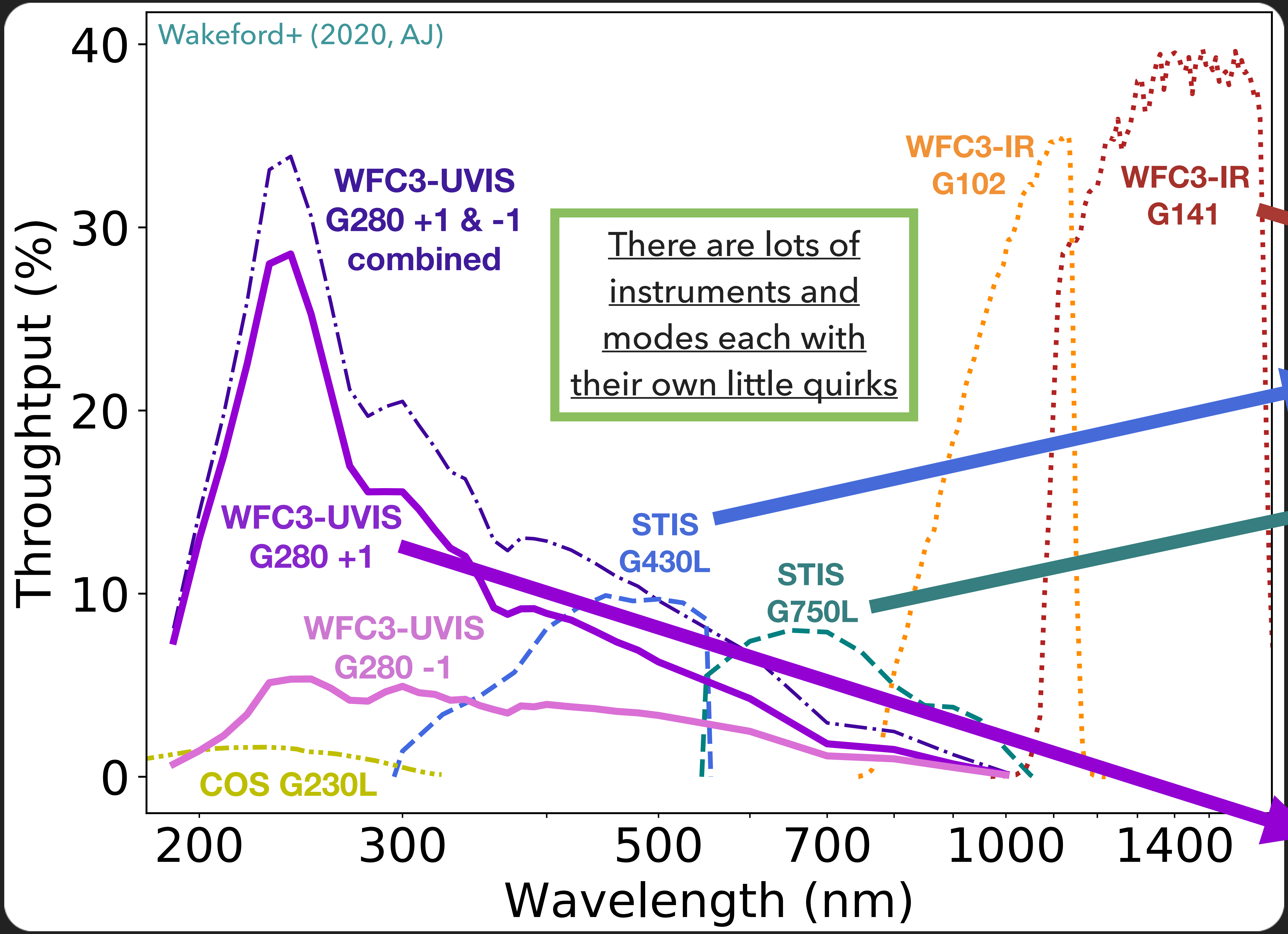
IR from 1 - 30 microns, low to high res spec, **chronography**

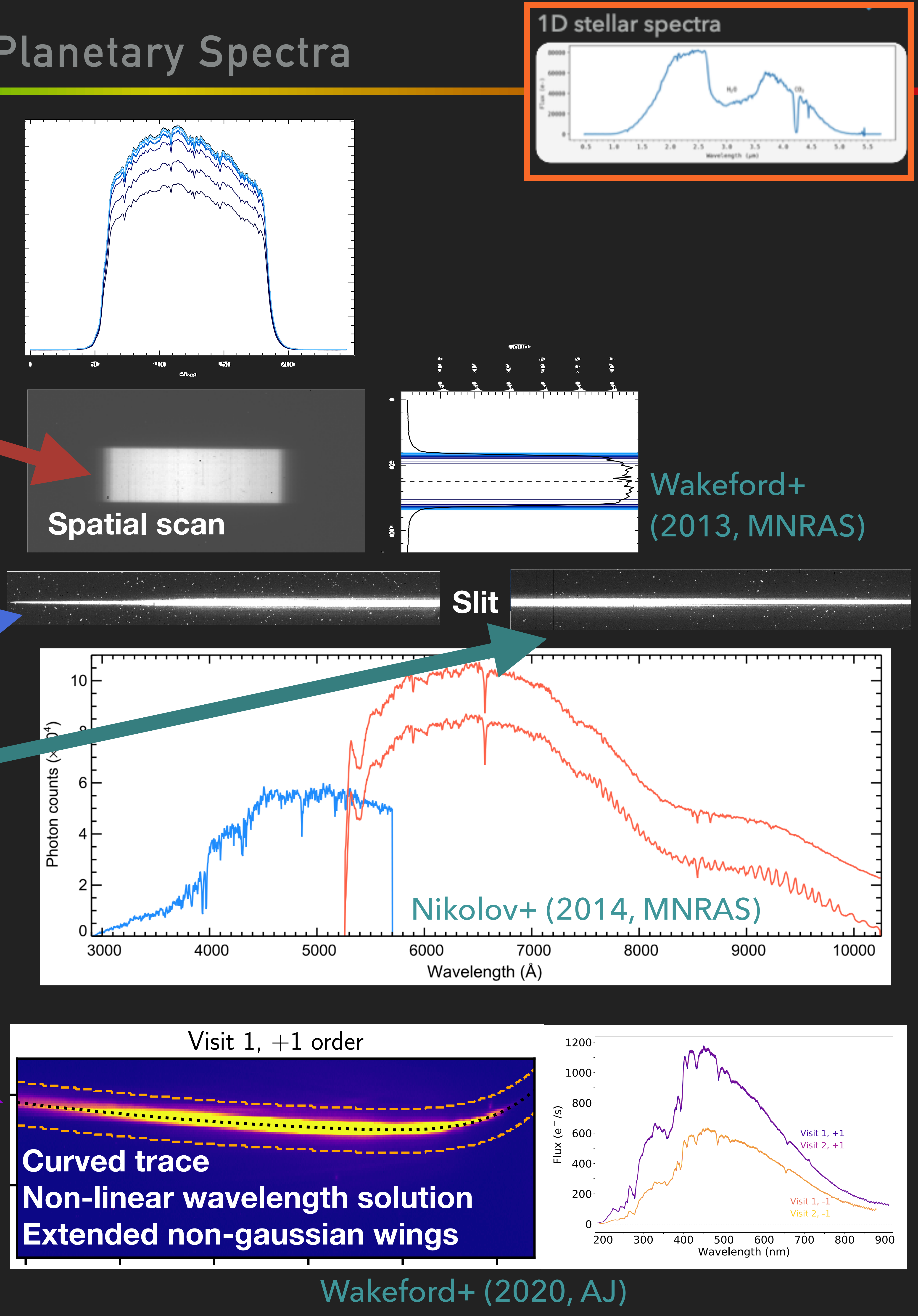
Cycle 1 proposal call showed the exoplanet community has at least a 25% stake in the future jobs of Webb

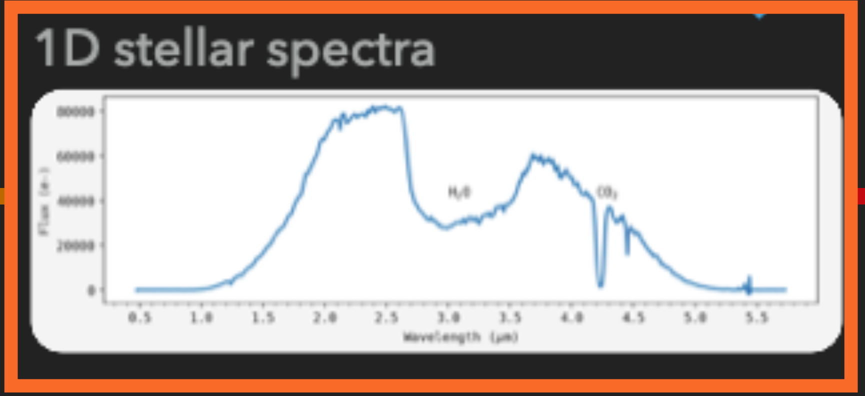
GTO + ERS + GO time is ~27% of time given out.

NO INSTRUMENT IS ALIKE...

LEARNING FROM HUBBLE

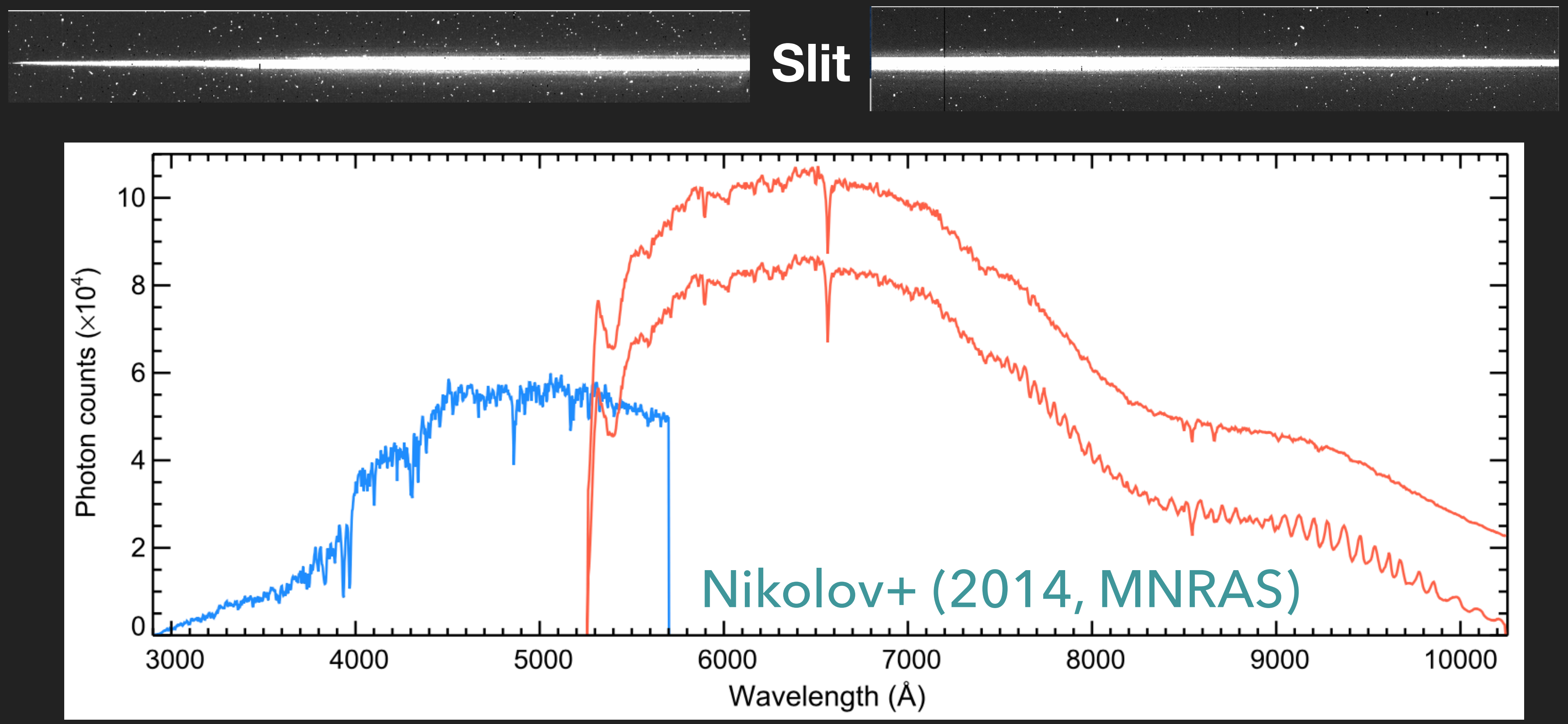




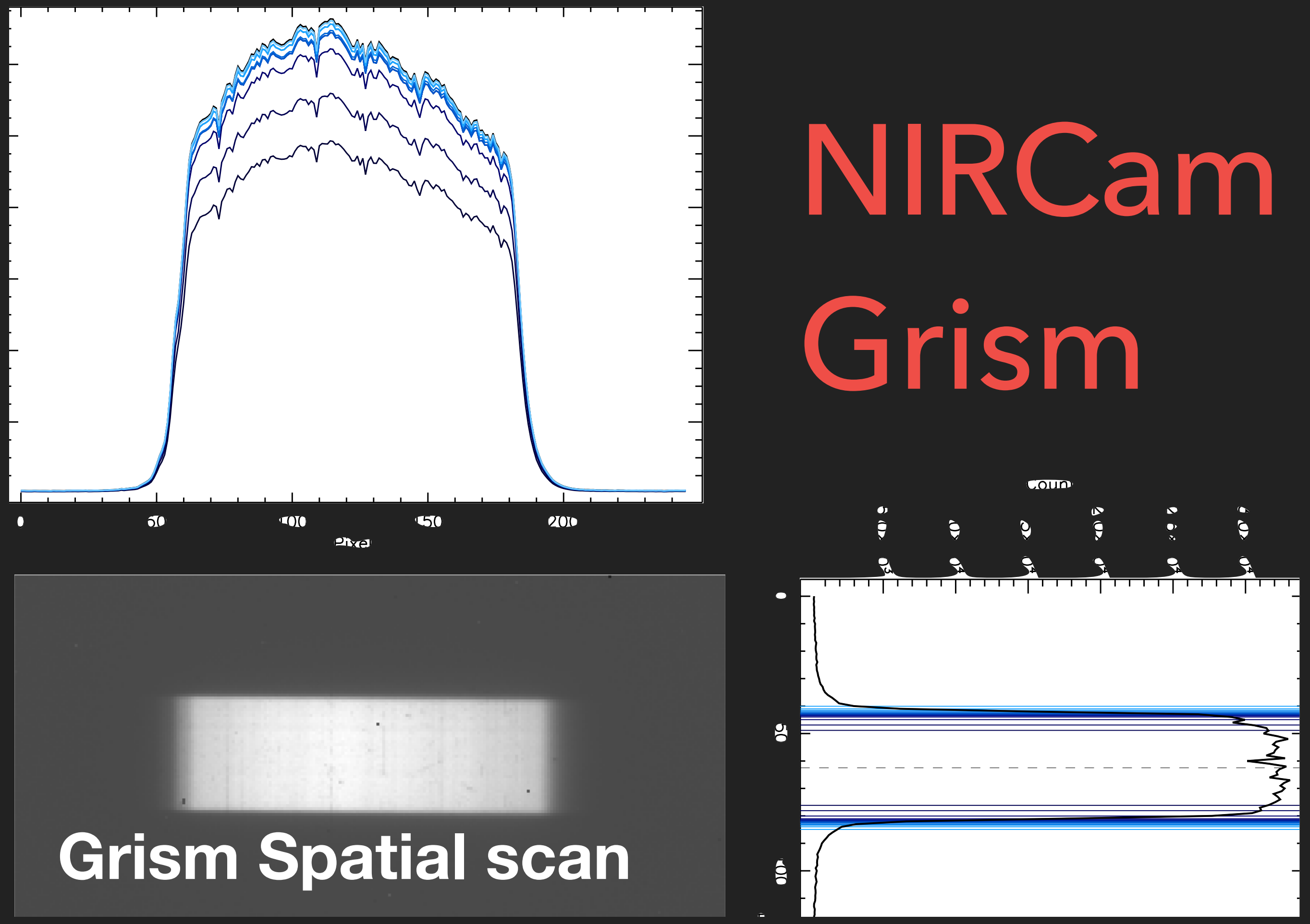


...BUT THERE ARE SOME SIMILARITIES TO WEBB

STIS G430L & G750L

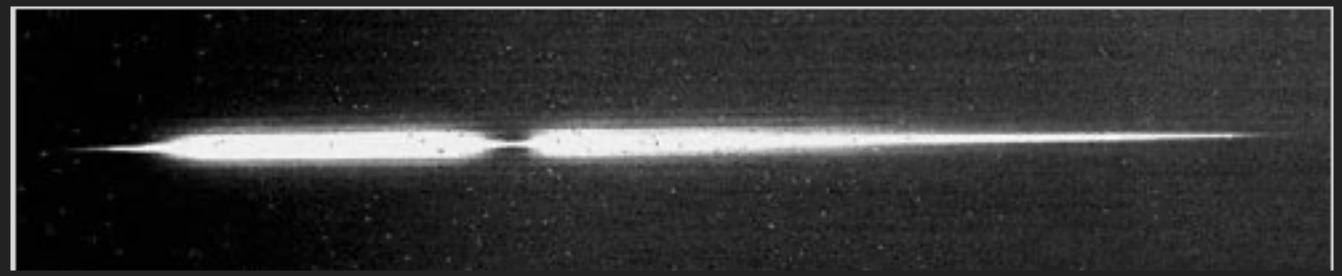


WFC3-IR Grism

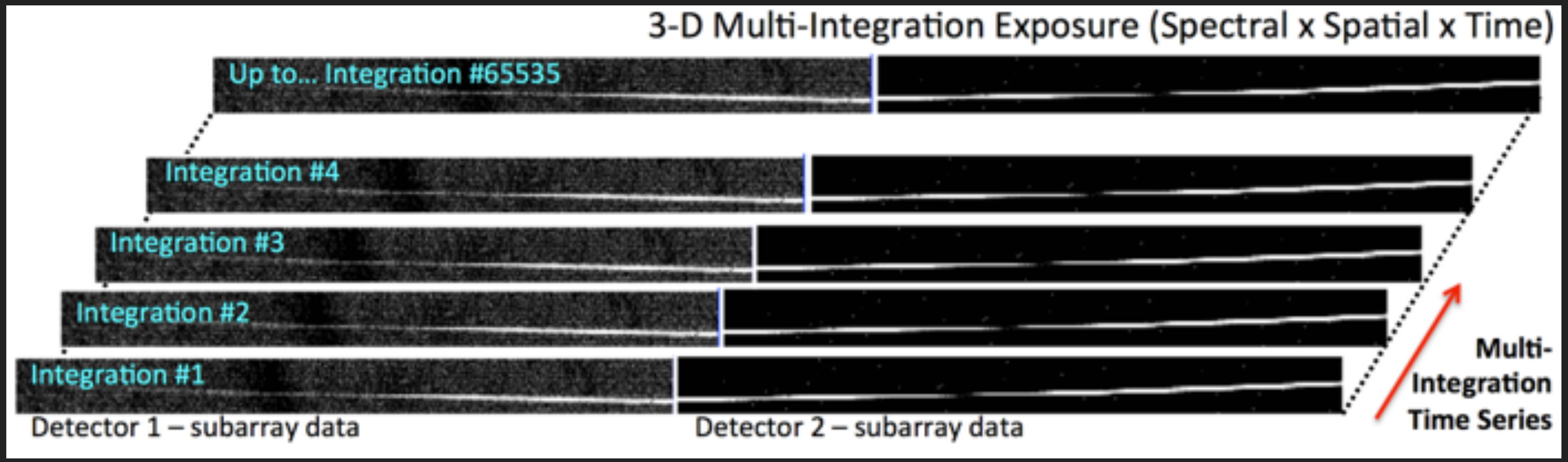


Wakeford+ (2013, MNRAS)

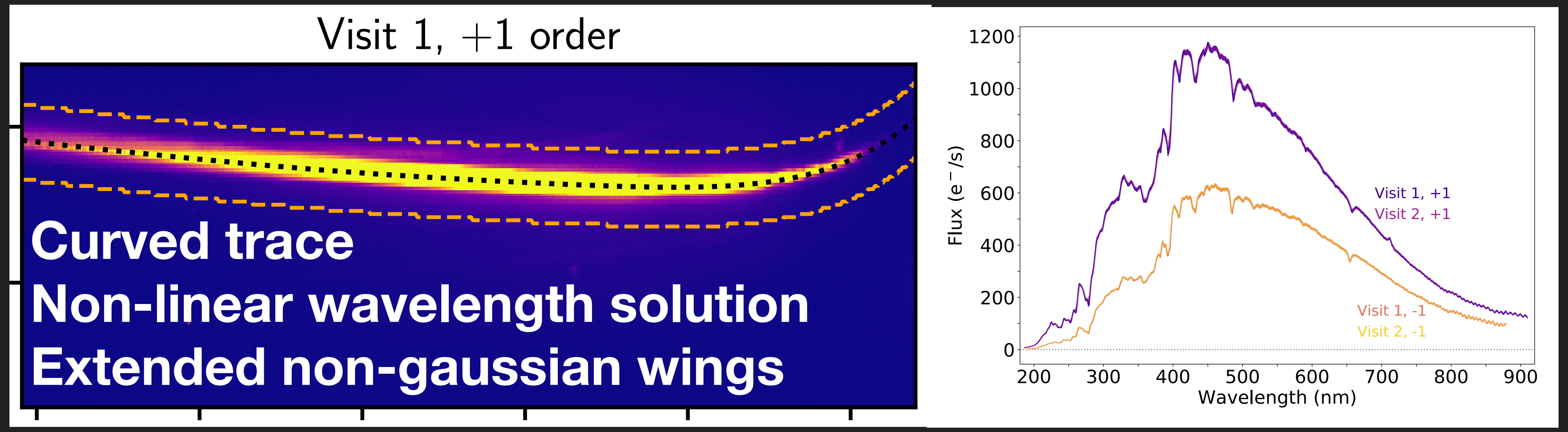
NIRCam Grism



NIRSpec BOTS

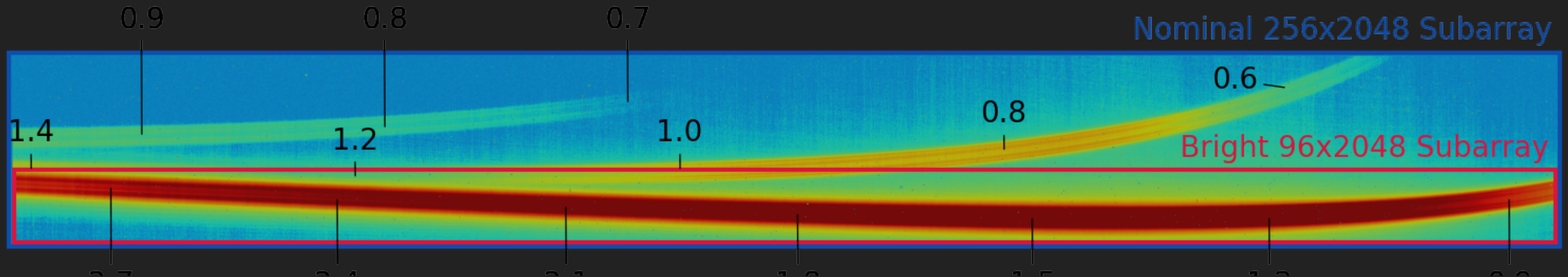


WFC3-UVIS Grism



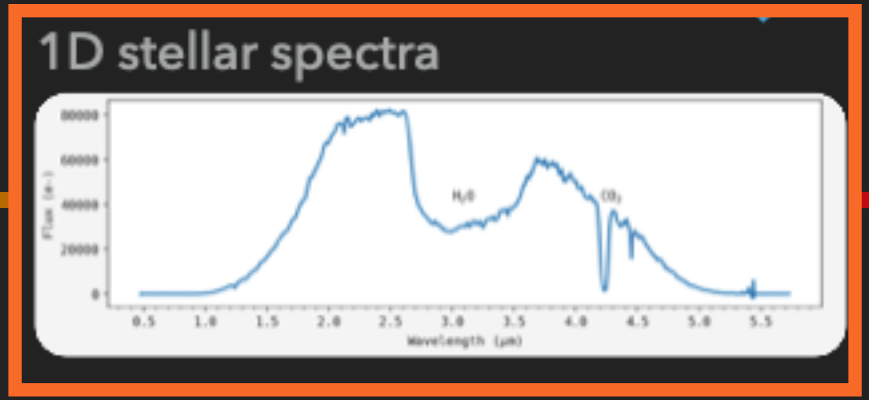
Wakeford+ (2020, AJ)

NIRISS SOSS



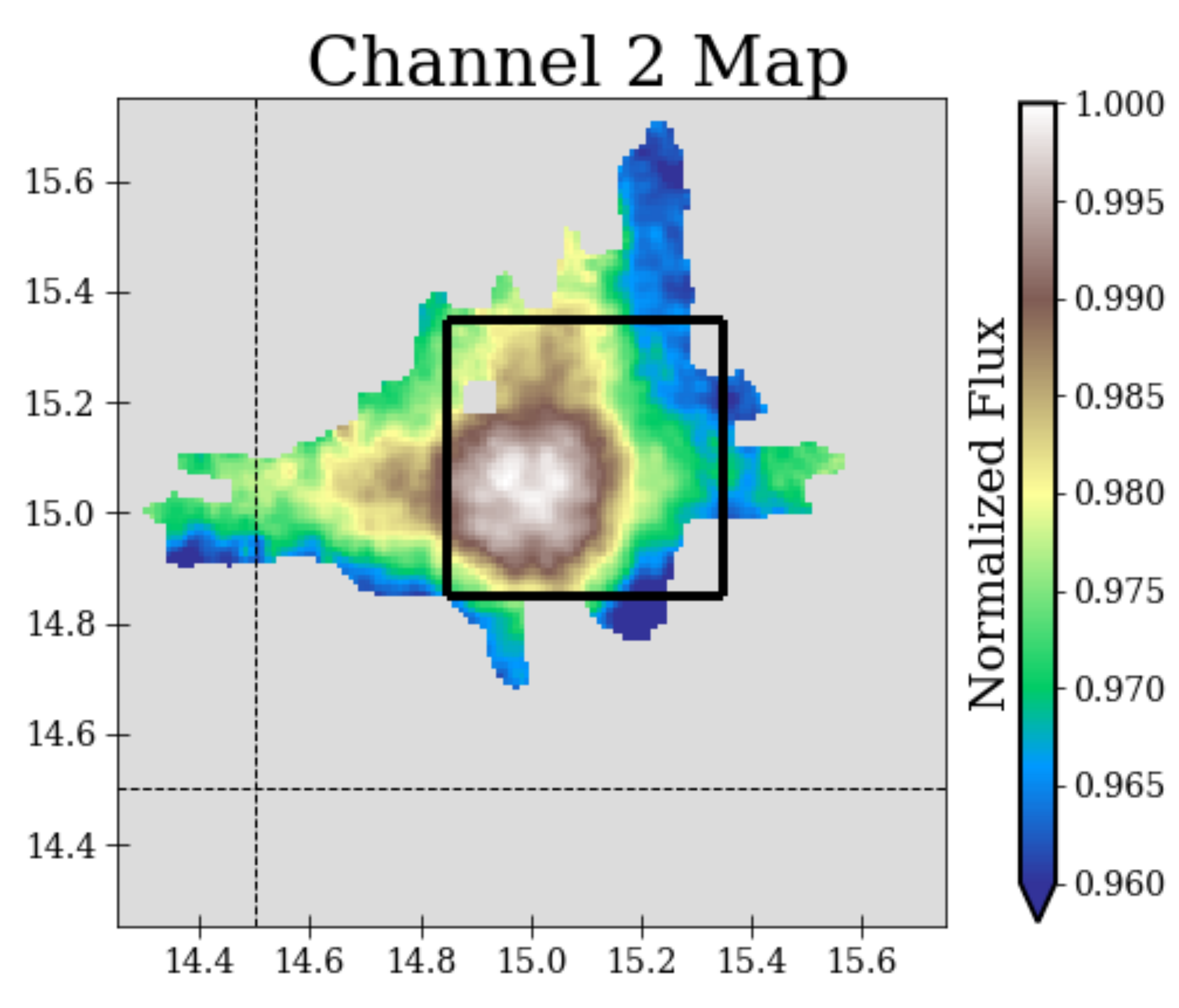
WHAT WE HAVE LEARNT FROM THE OBSERVATIONS

High-cadence long-duration time-series observations reveal many ‘hidden’ secrets of space-based observatories….



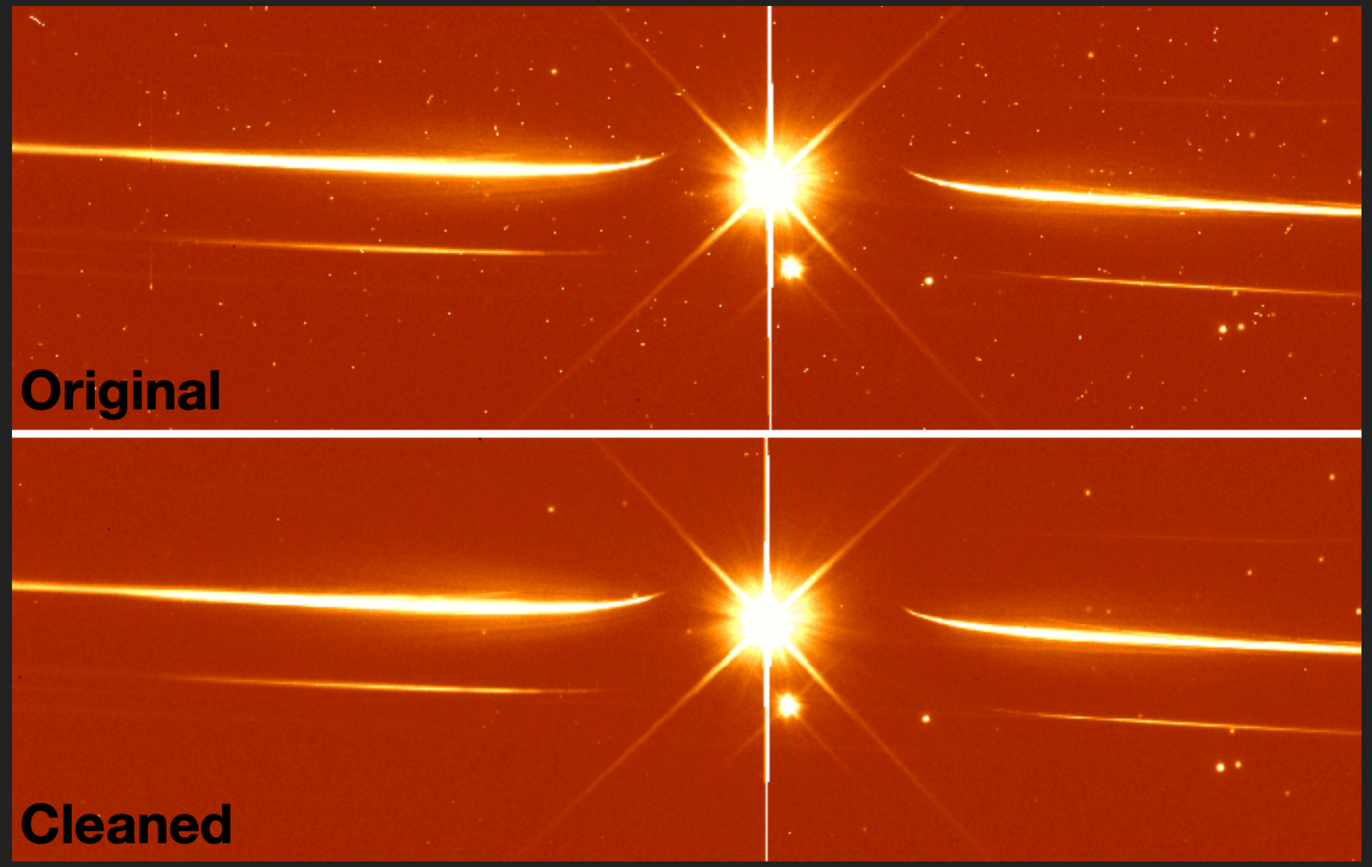
SOME OF THE 1ST ORDER EFFECTS TO CONSIDER

Pixel Sensitivity Maps

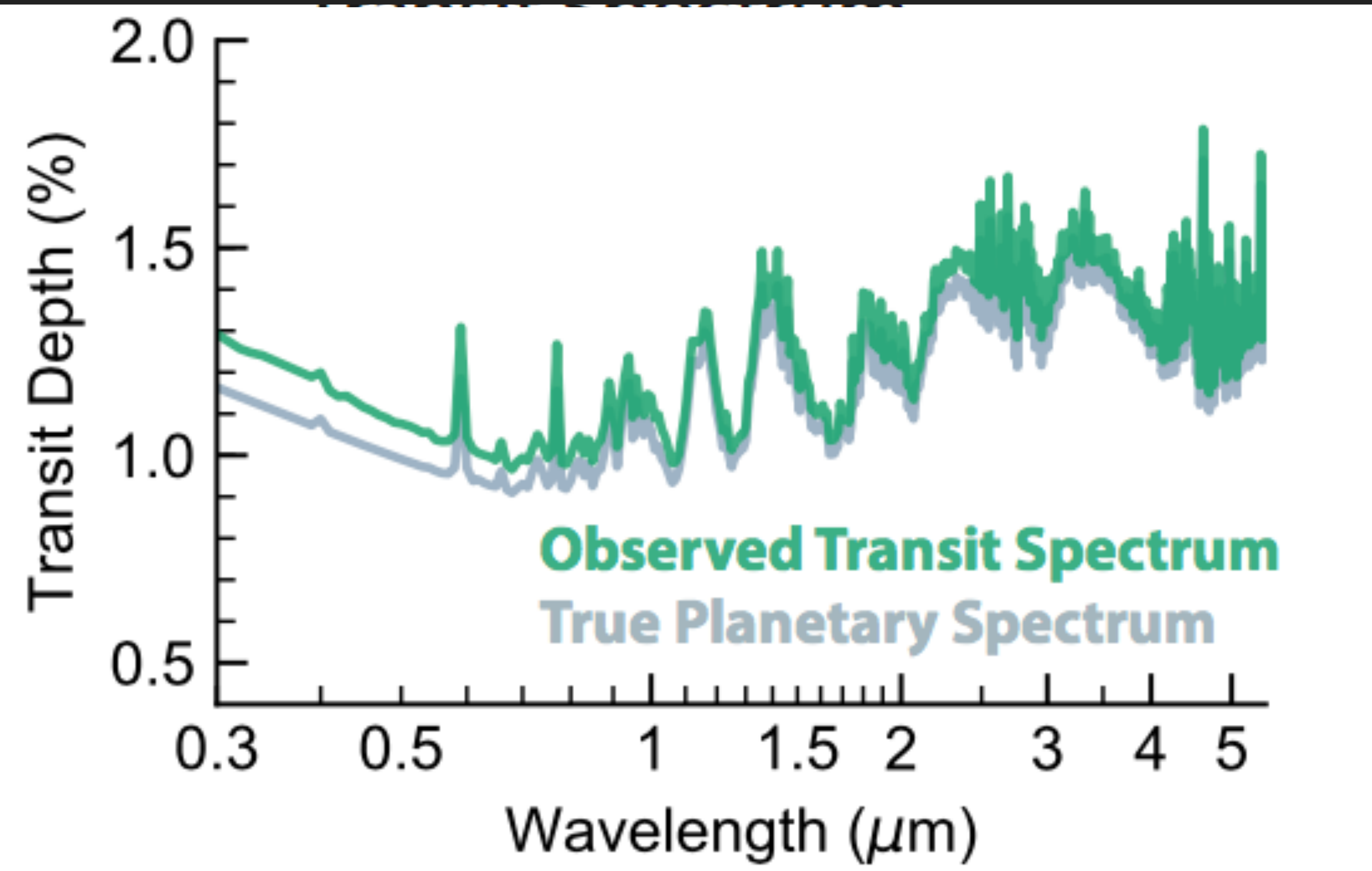


May+ (2020)

Cosmic rays & Background

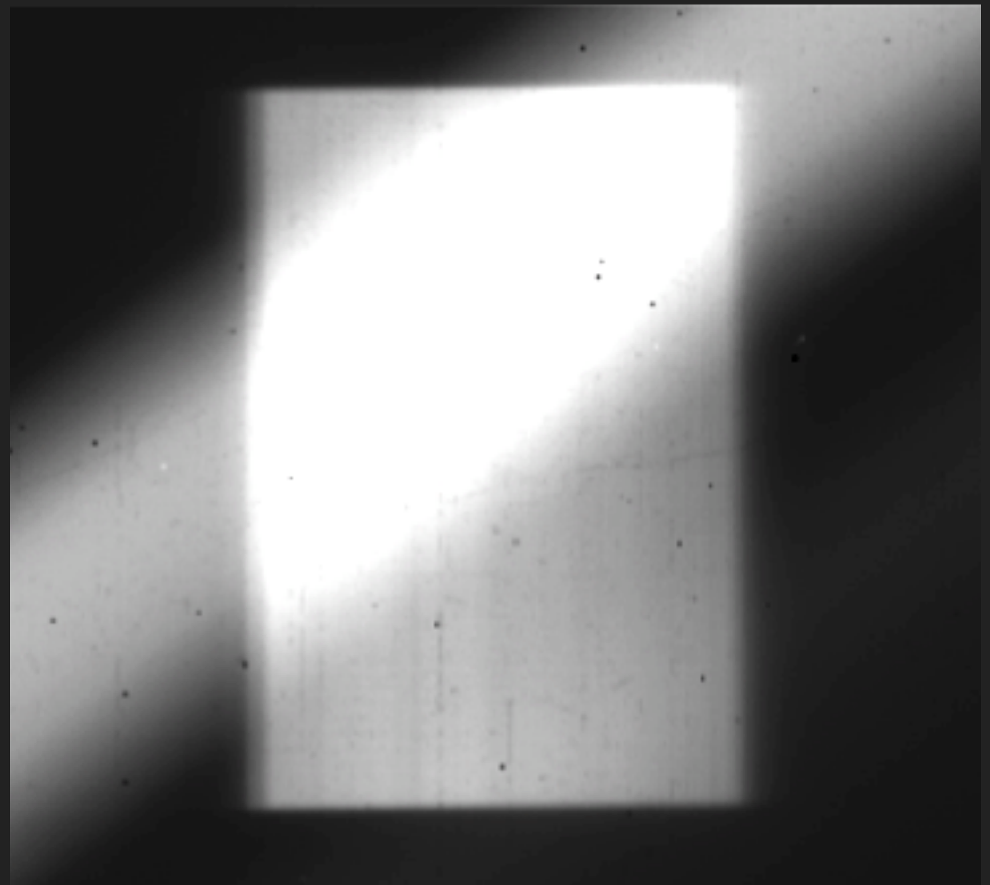


Stellar Inhomogeneties

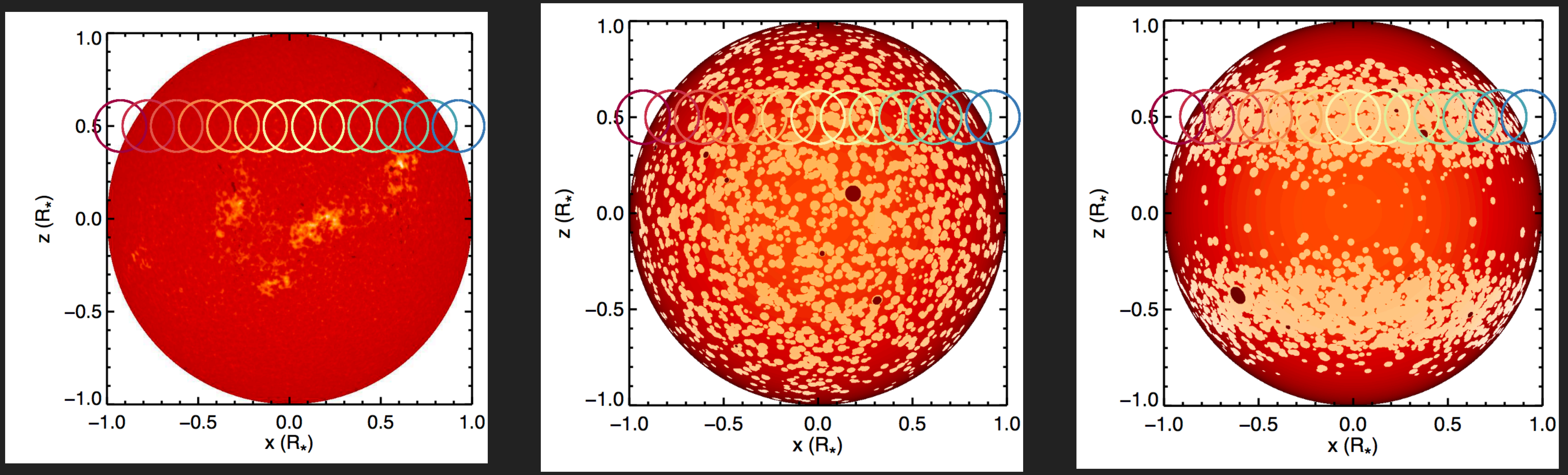


Rackham+ (2018)

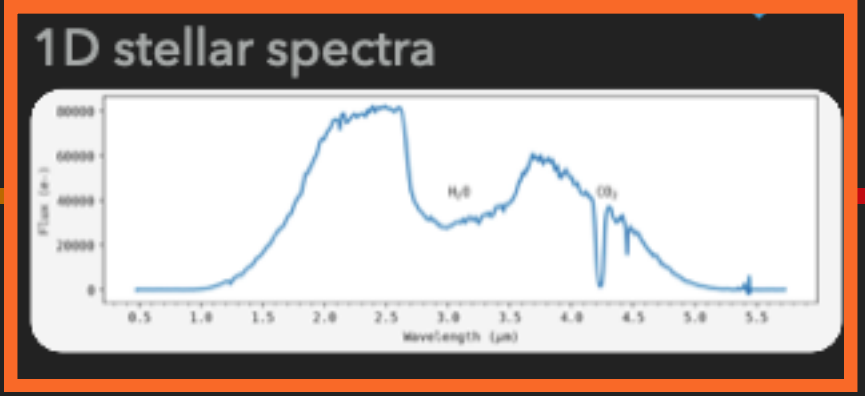
Transitent Events



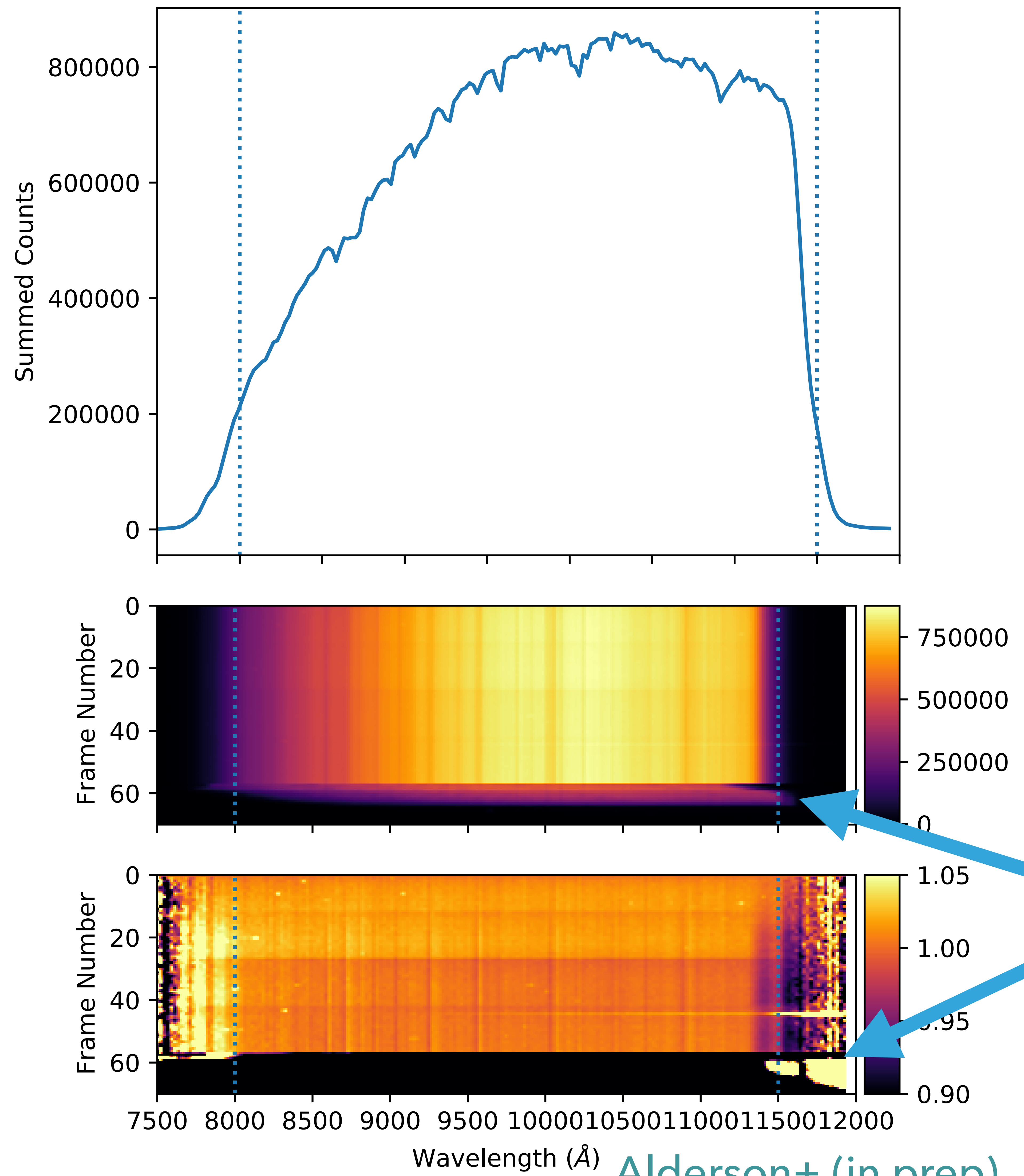
Fu+ (2020, AJ)



Cauley+ (2018)

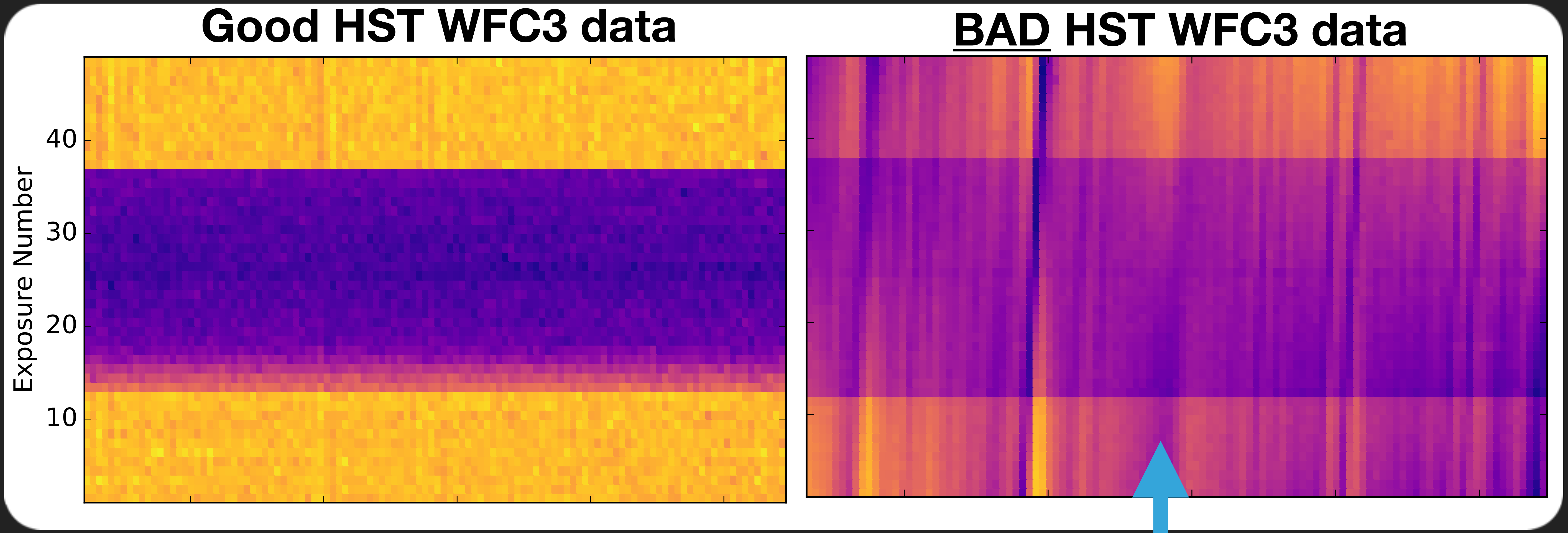


VISUALIZING YOUR 1D STELLAR SPECTRA AS PIXEL MAPS



Alderson+ (in prep)

Plotting the stellar spectra as a pixel map can help reveal issues in the data before analysis even starts

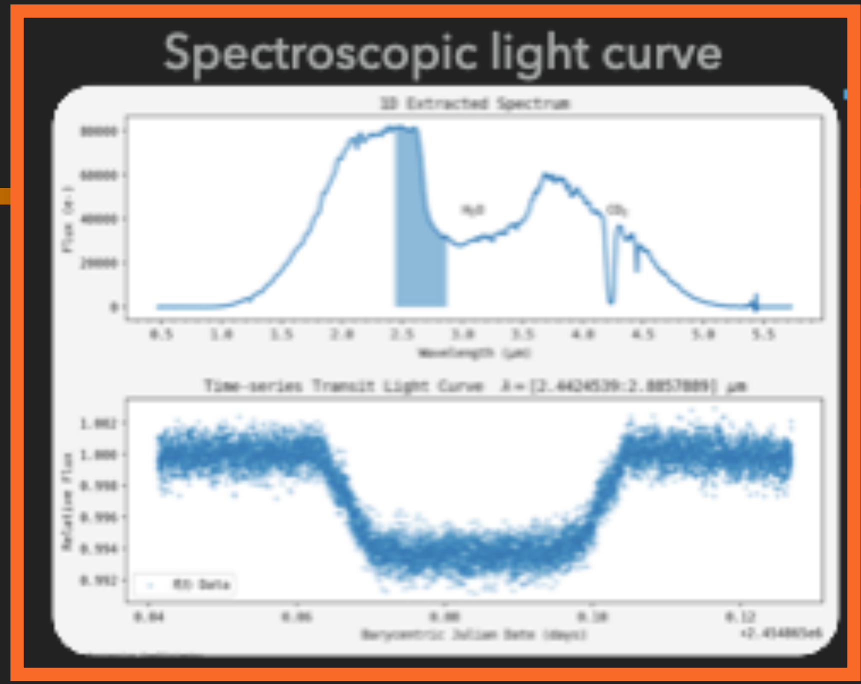


Pointing issues: Star drifting off the detector

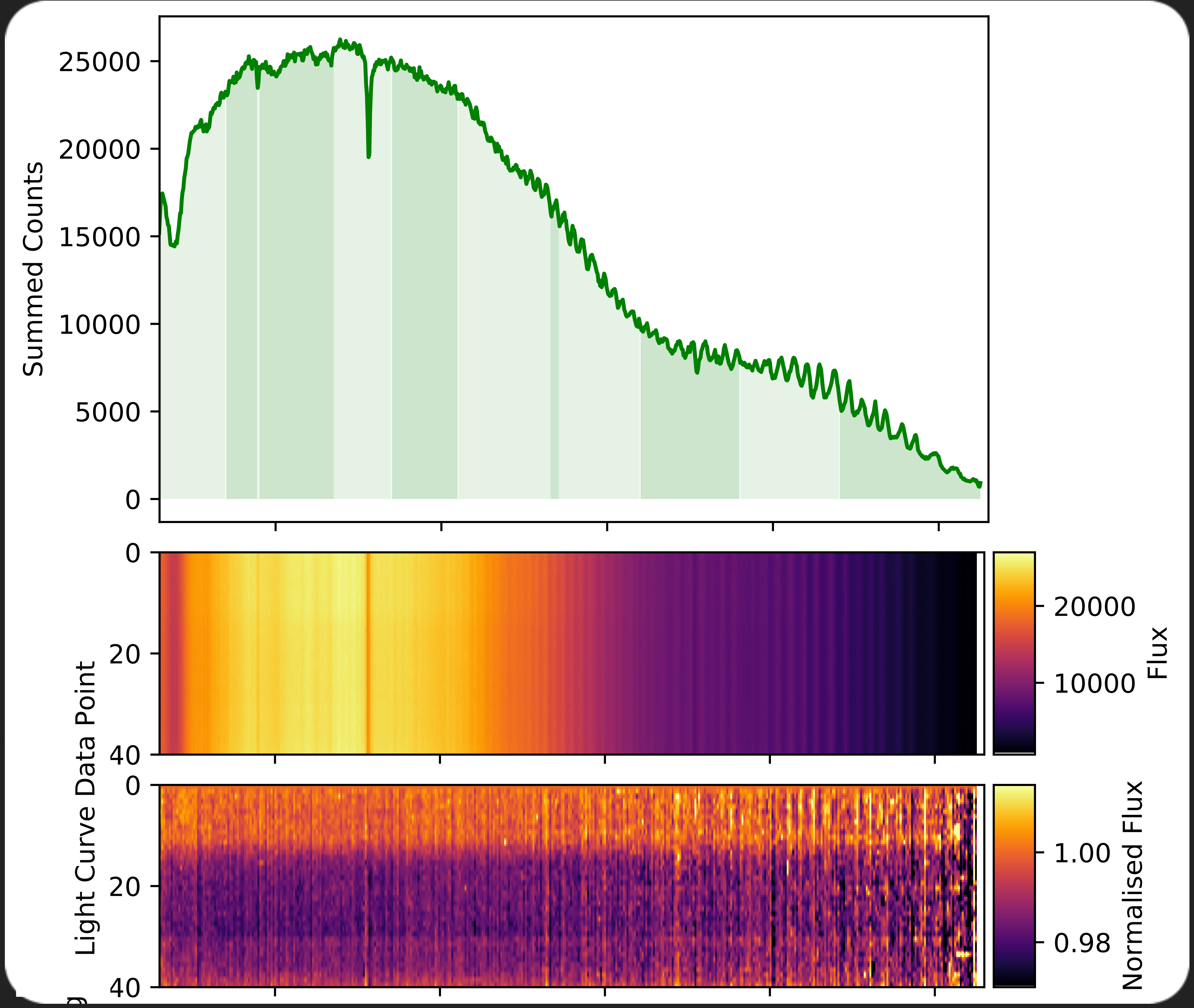
Lili Alderson, PhD Researcher, University of Bristol

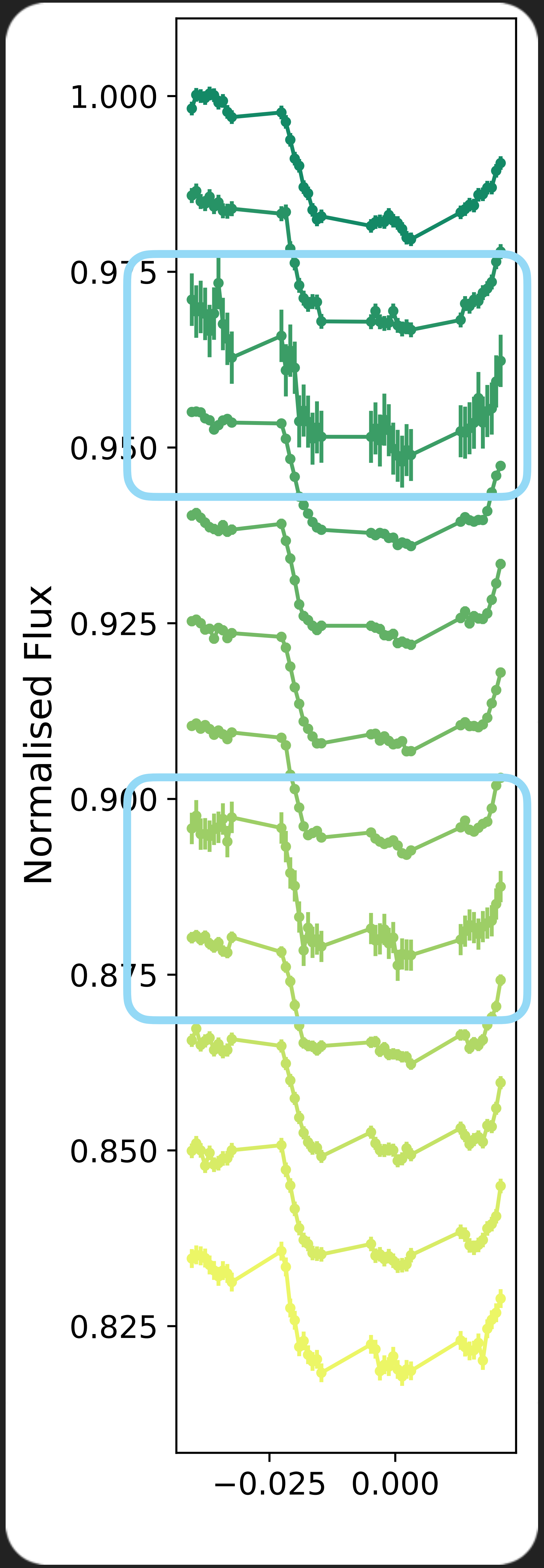
Warped scan shape inducing wavelength dependent cross-talk

Image credit: H.R.Wakeford published in Sing (2018 book chapter)



BINNING YOUR SPECTRUM





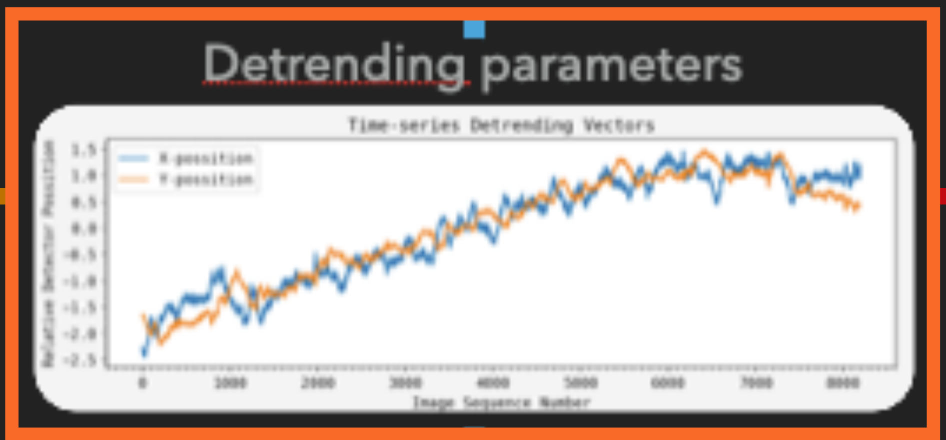
Bins are often determined by the features you are searching for.

The two narrow bins here are centered on the atomic Na and K lines in the optical.

Broader molecular features often benefit from even bin widths

Alderson+ (in prep)

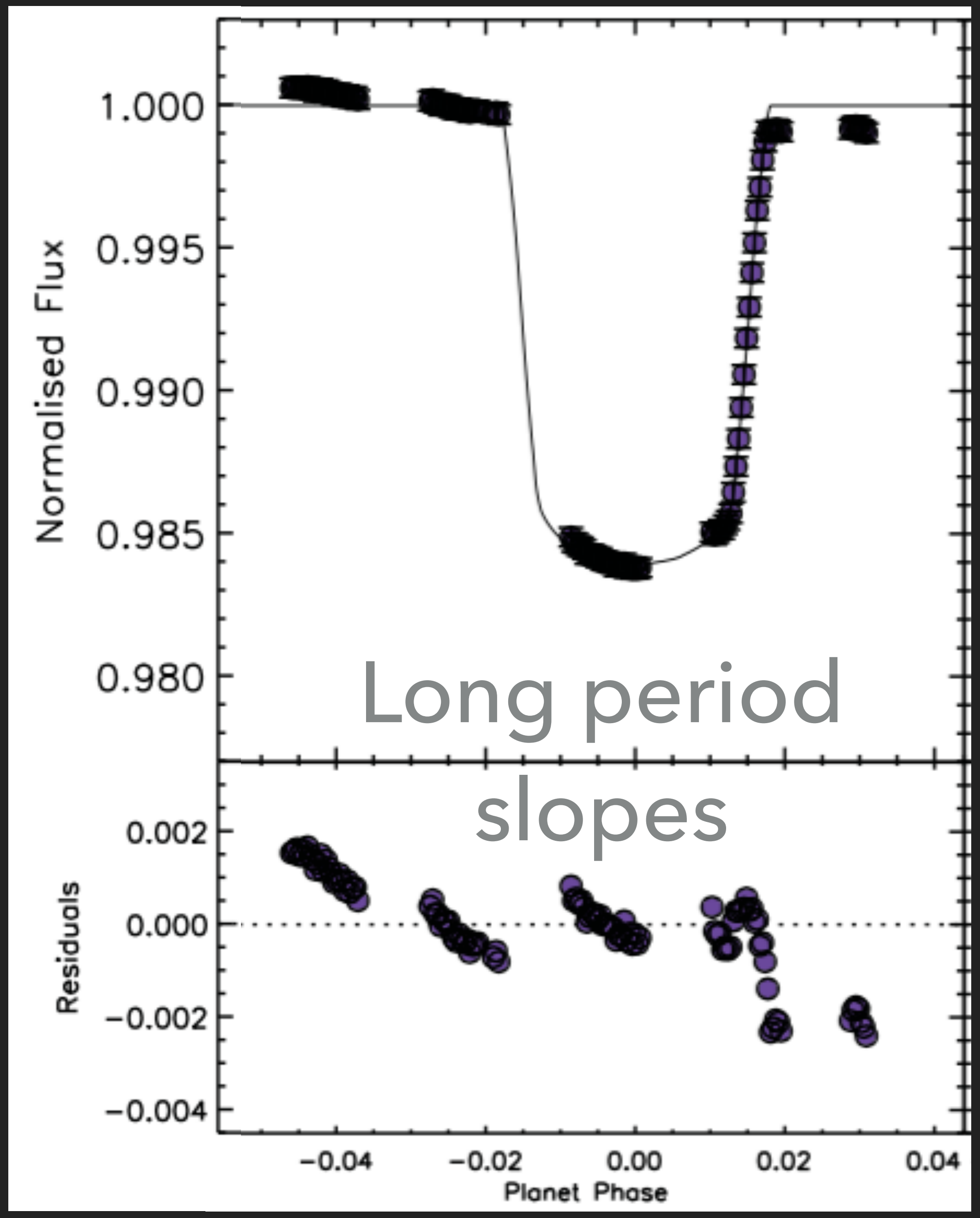
Lili Alderson,
PhD Researcher,
University of Bristol

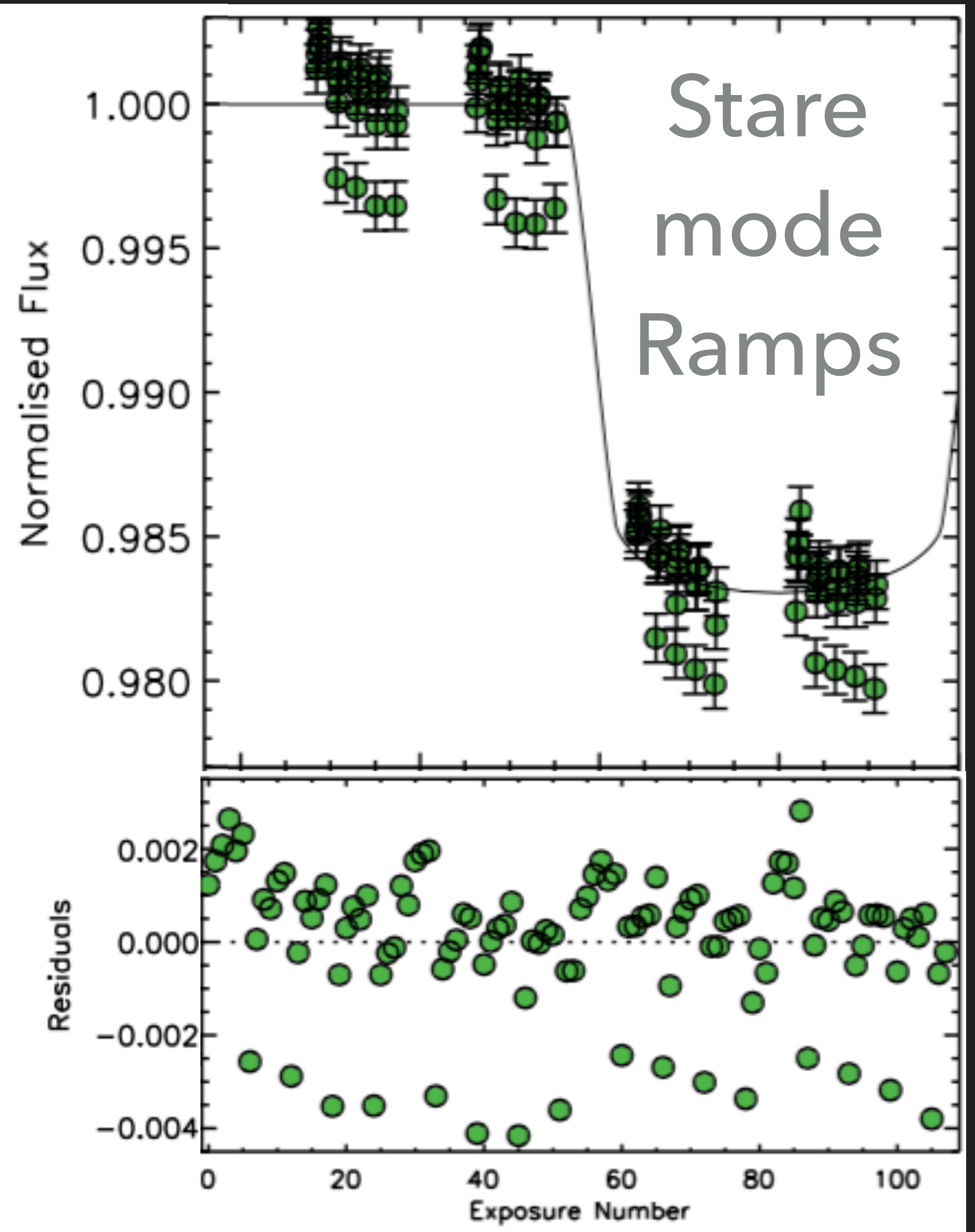


TIME SERIES SYSTEMATICS COME IN MANY SHAPES AND FORMS

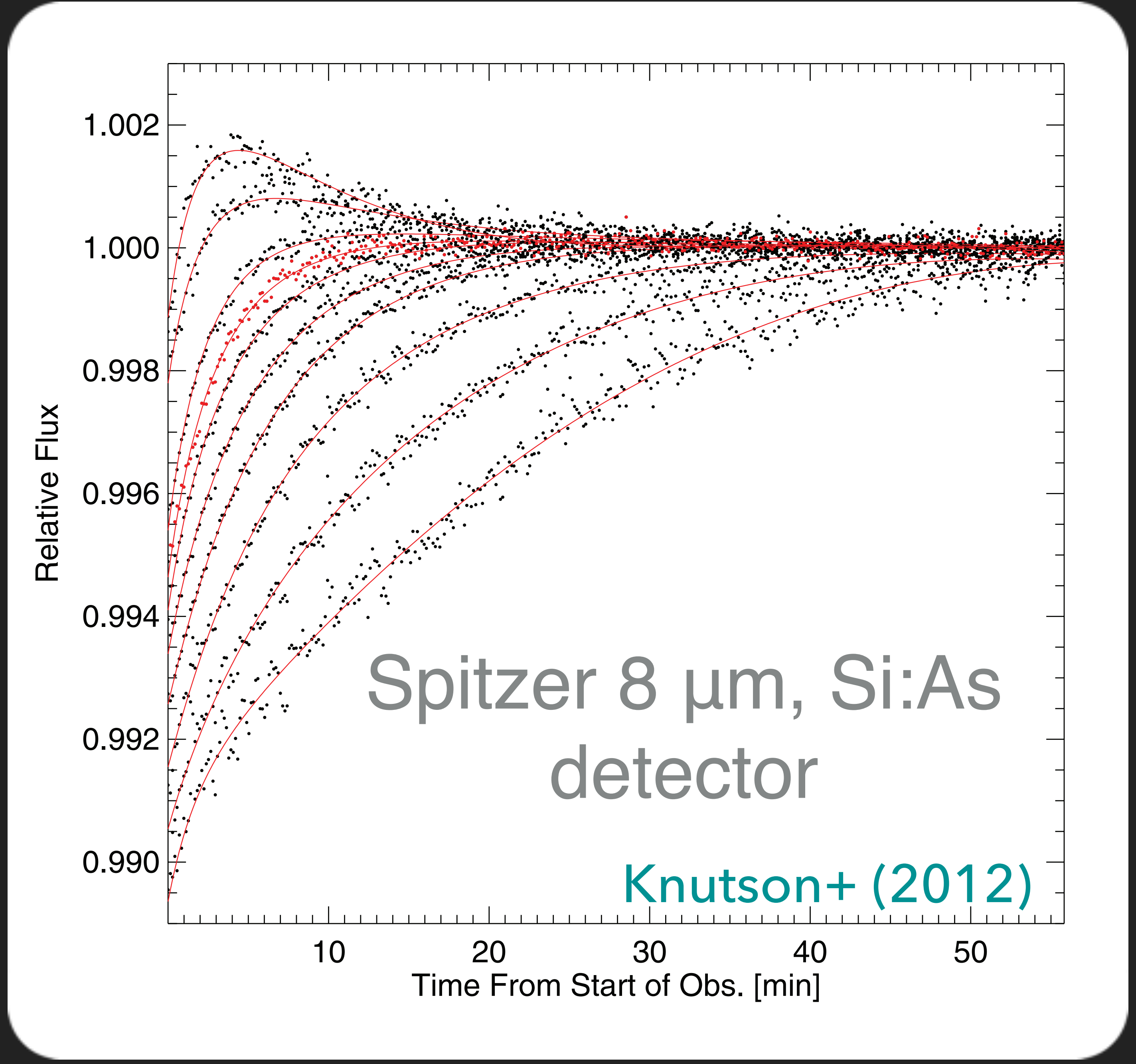
Instrument & Detector Ramps

All time series observations have time variable trends. Many detectors have "ramp" effects due to charge build up or trapping



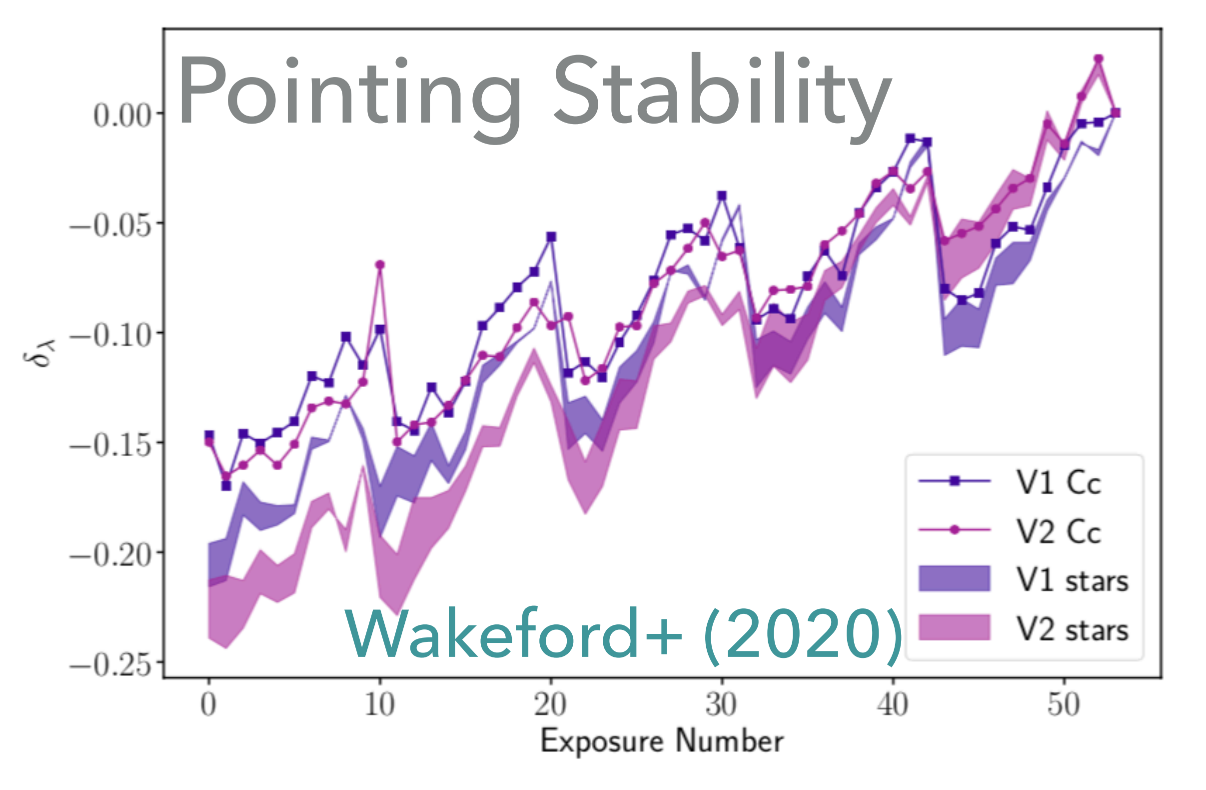


Wakeford+ (2016)

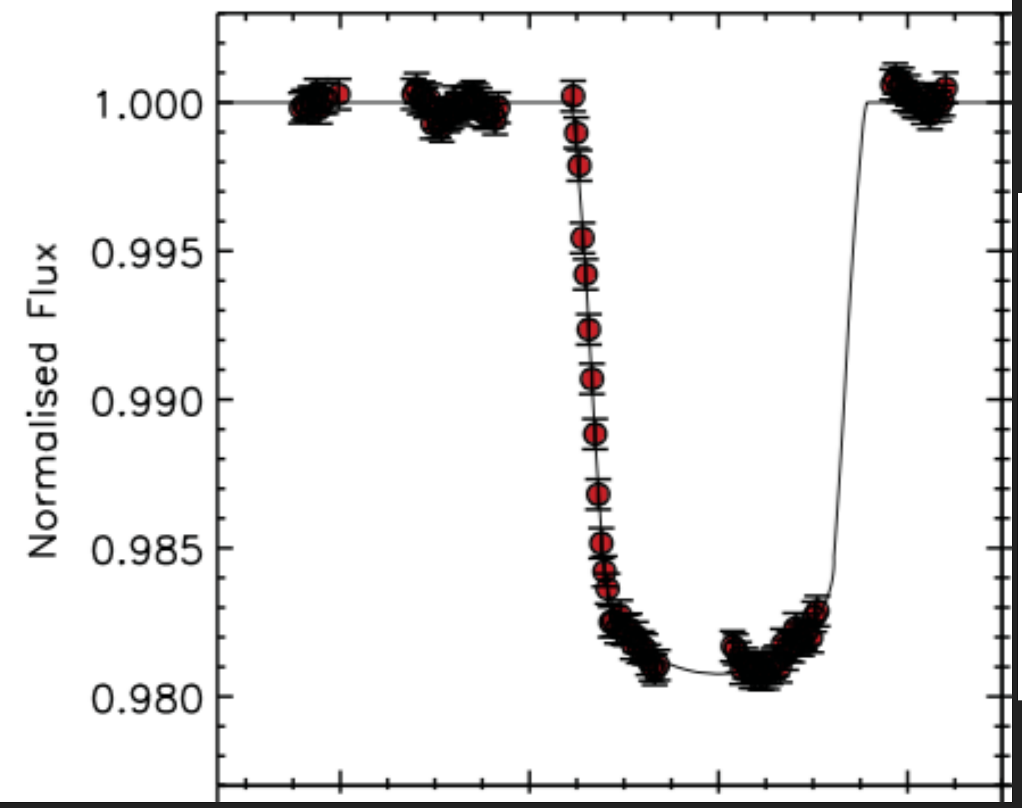


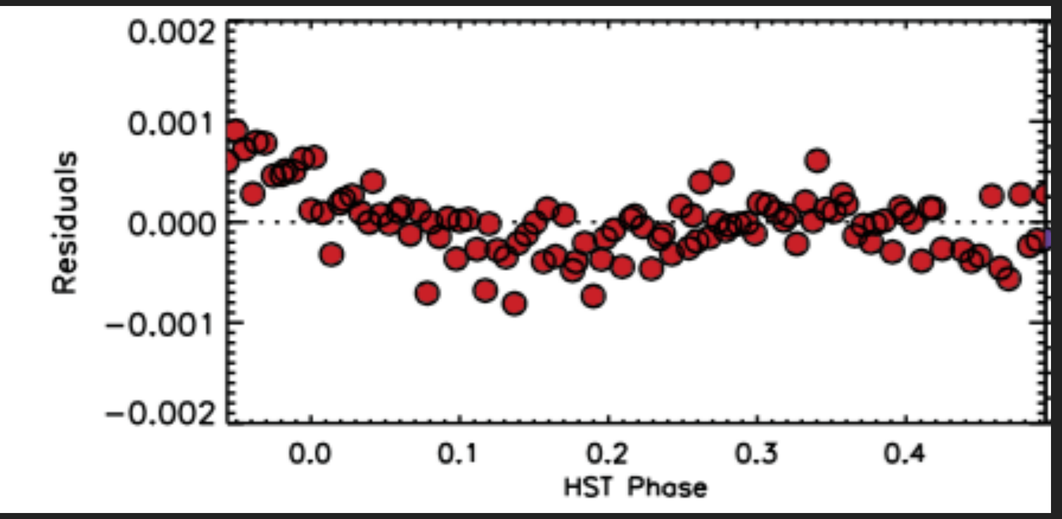
Telescope Ramps

Global impact of thermal and pointing from the whole observatory/telescope

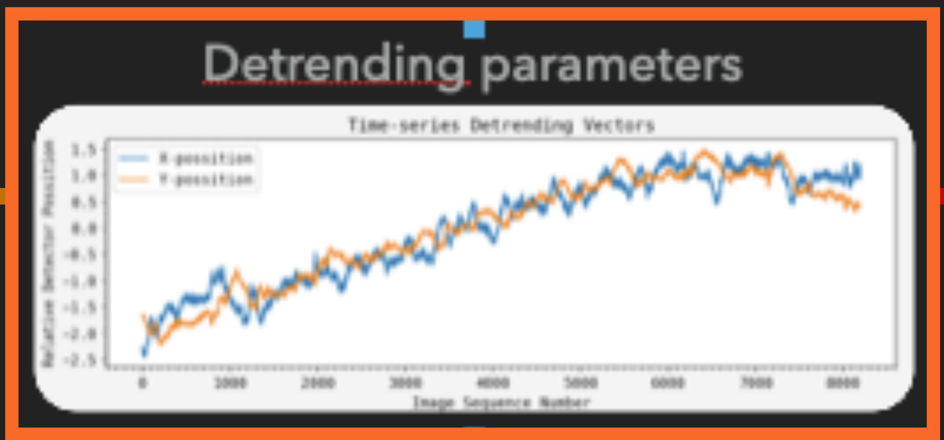


Thermal "breathing"





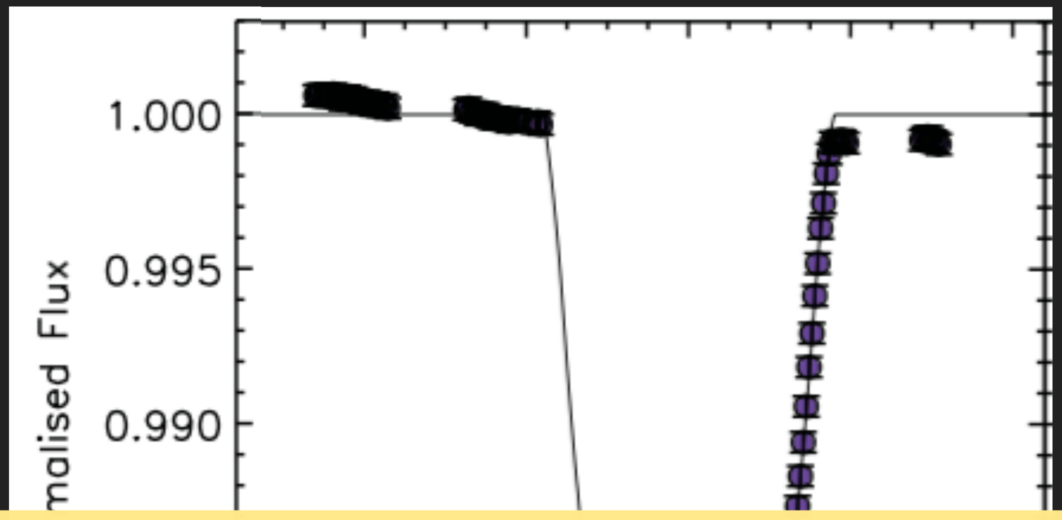
Wakeford+ (2016)

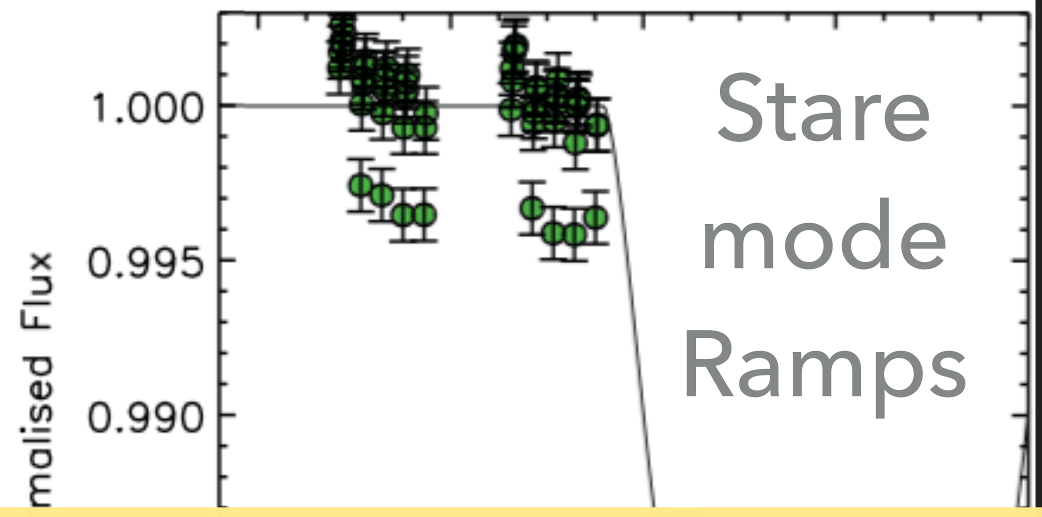


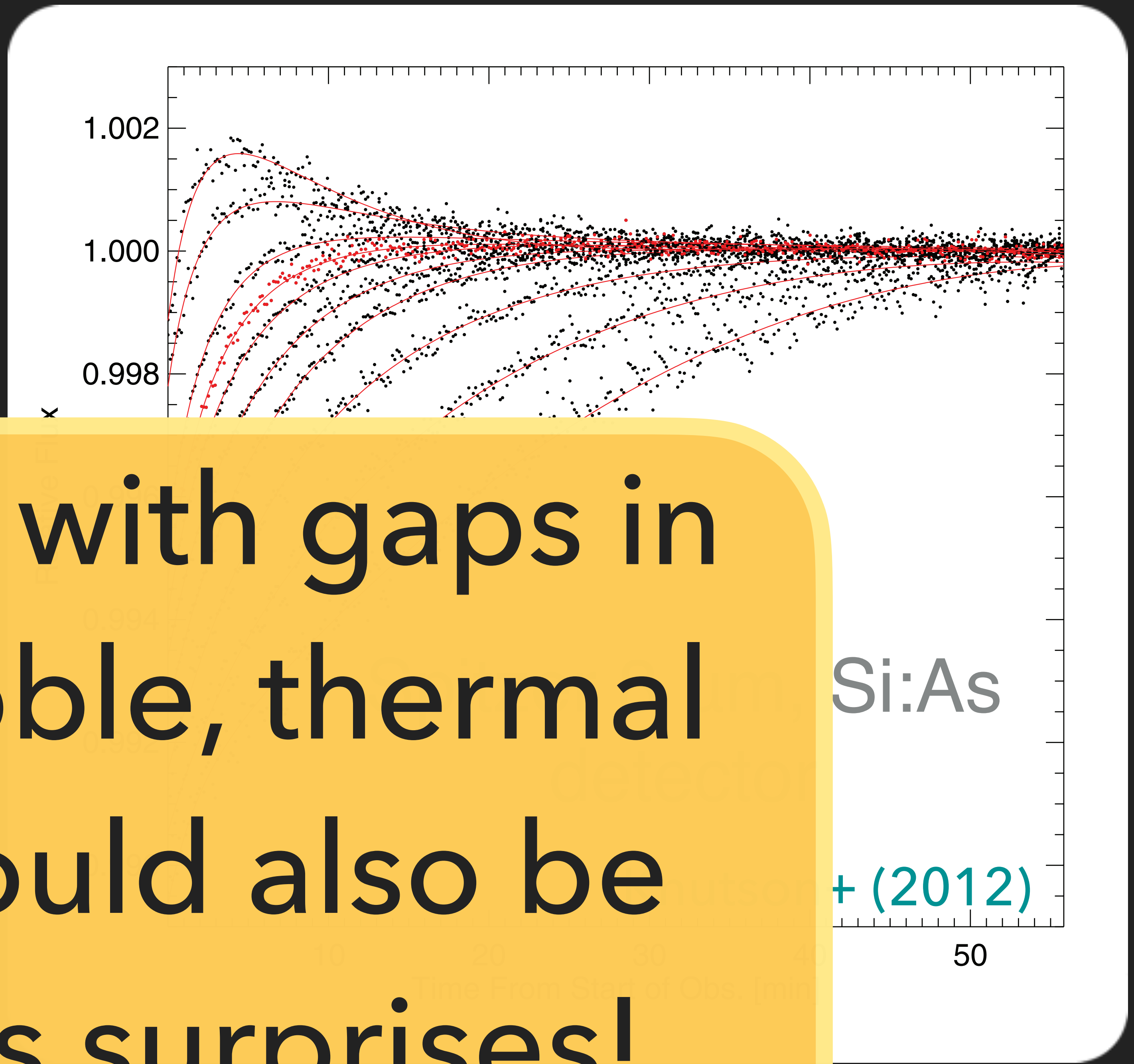
TIME SERIES SYSTEMATICS COME IN MANY SHAPES AND FORMS

Instrument & Detector Ra

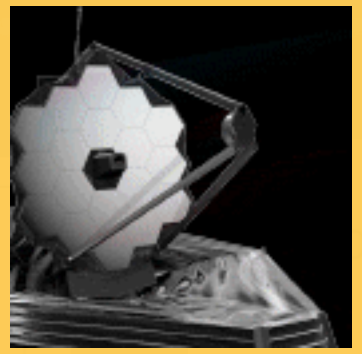
All time ser
have time
Many detec
effects due t
or t





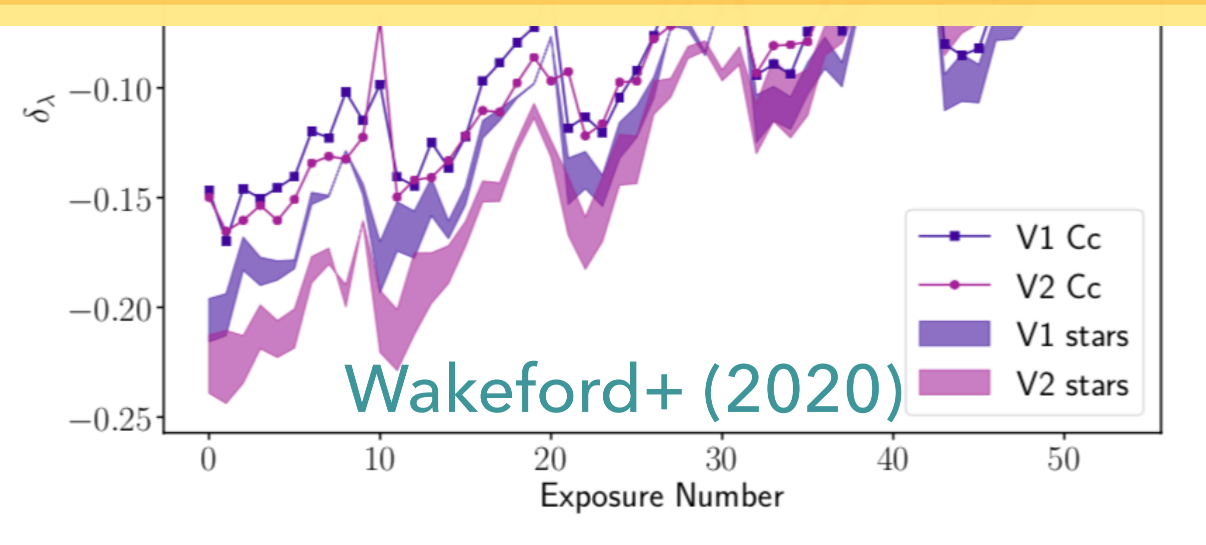


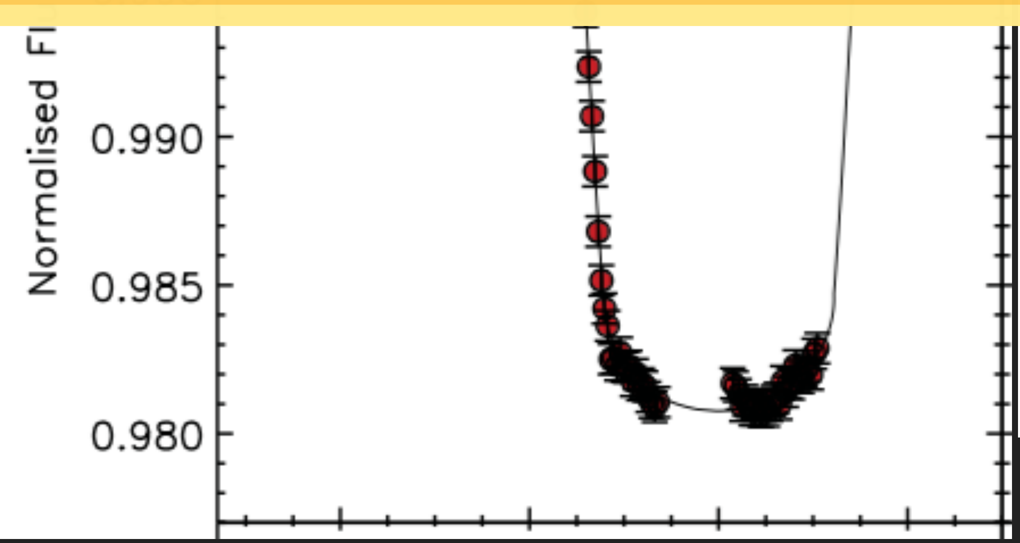
With Webb we will not need to deal with gaps in the observation like we do with Hubble, thermal breathing and pointing stability should also be smaller effects, but there are always surprises!

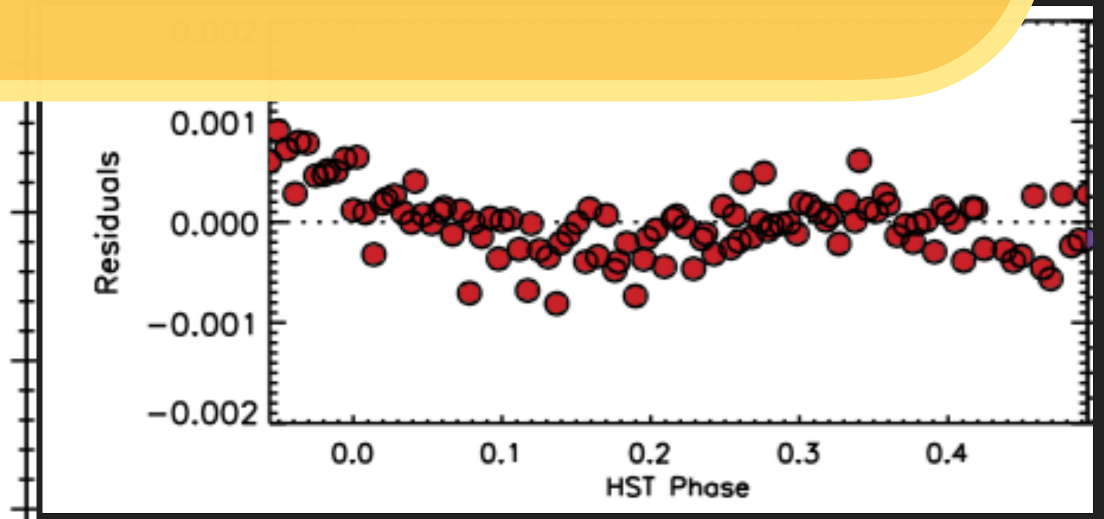


Tele Ra

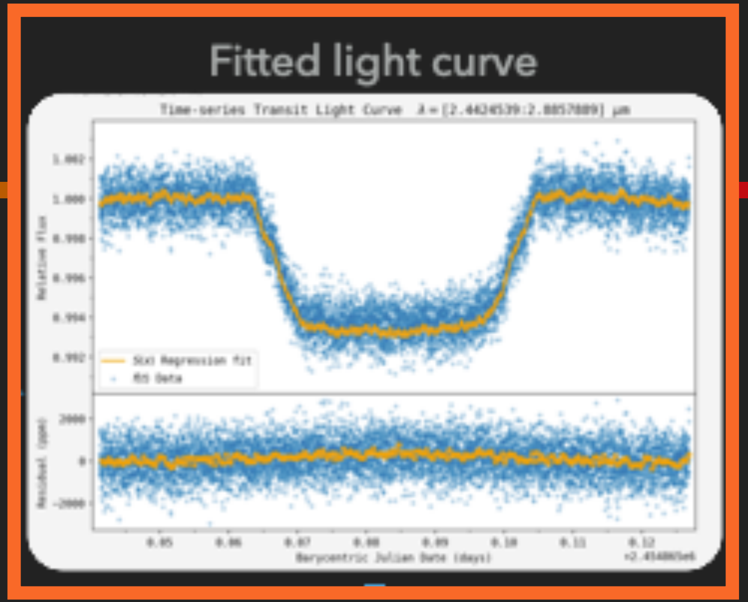
Global impact of thermal and pointing from the whole observatory/telescope







Wakeford+ (2016)



WHAT IS USED TO CORRECT ALL OF THIS

Models

Simple

Single systematic models

Common-mode wavelength independent model

Complex

Marginalization

Jitter decorrelation

GP

Solver

Least-square minimizer — Fastest →

MCMC — Slow →

GP — Faster

Parameter Estimation

Single uncertainty on parameters

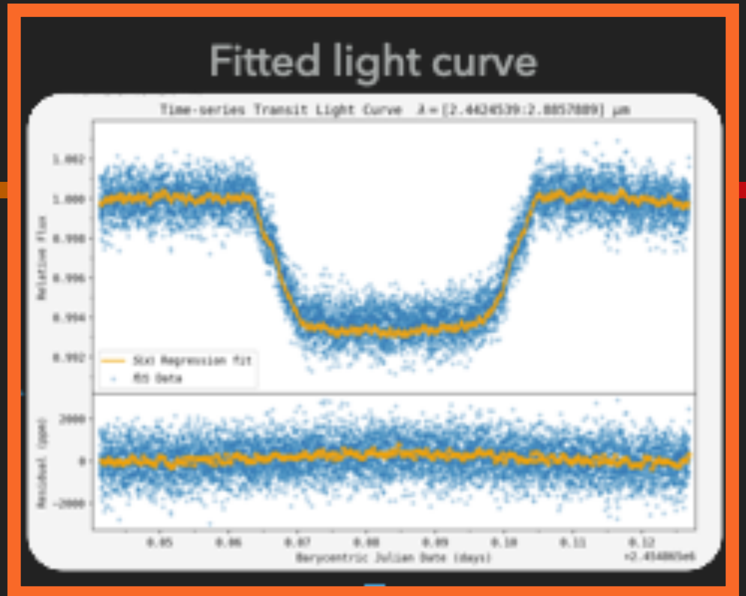
Output covariance matrix

Full posterior of estimated parameters

Correlation between parameters

The larger suite of models considered, the smaller the space assigned to the probability that none of your models can explain your data.

See Gibson (2014, MNRAS) for examples of model treatments



WHAT IS USED TO CORRECT ALL OF THIS

Models

Simple

Single systematic models

Common-mode wavelength independent model

Complex

Marginalization

Jitter decorrelation

GP

Solver

Least-square minimizer — Fastest →

MCMC — Slow →

GP — Faster →

Parameter Estimation

Single uncertainty on parameters

Output covariance matrix

Full posterior of estimated parameters

Correlation between parameters

The larger suite of models considered, the smaller the space assigned to the probability that none of your models can explain your data.

Example/Shameless Plug!

Complex and quick

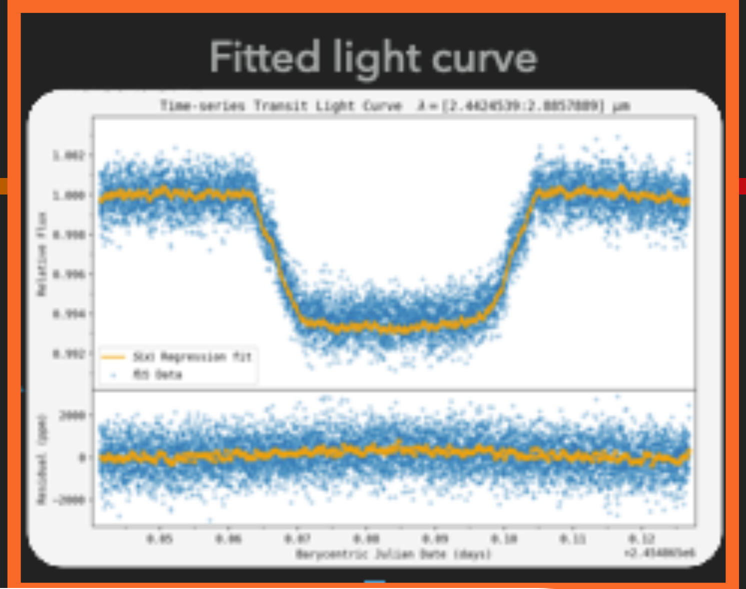
ExoTiC-ISM

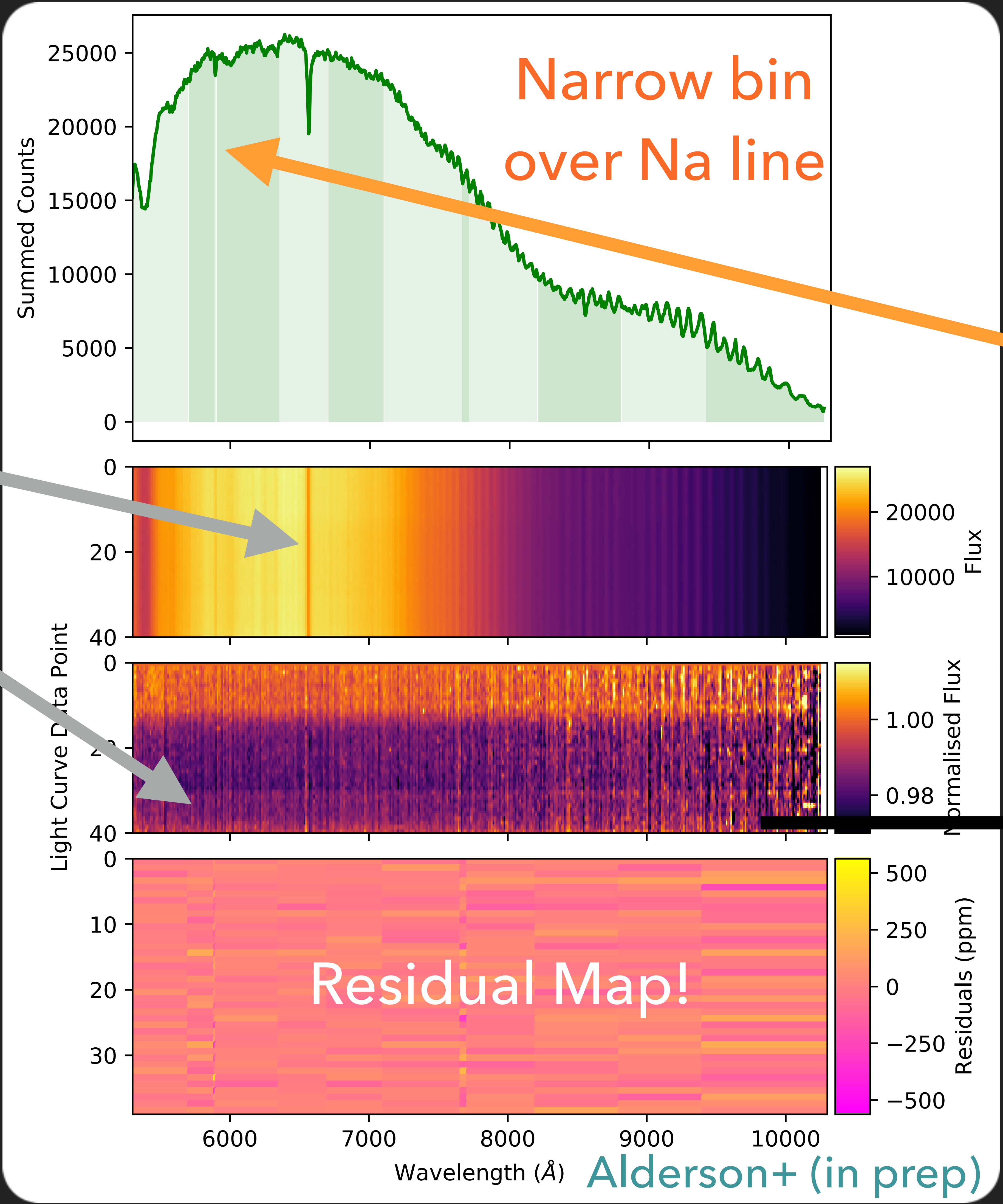
Instrument Systematic Marginalisation package with least-squares minimisation

Laginja & Wakeford (2020, JOSS)

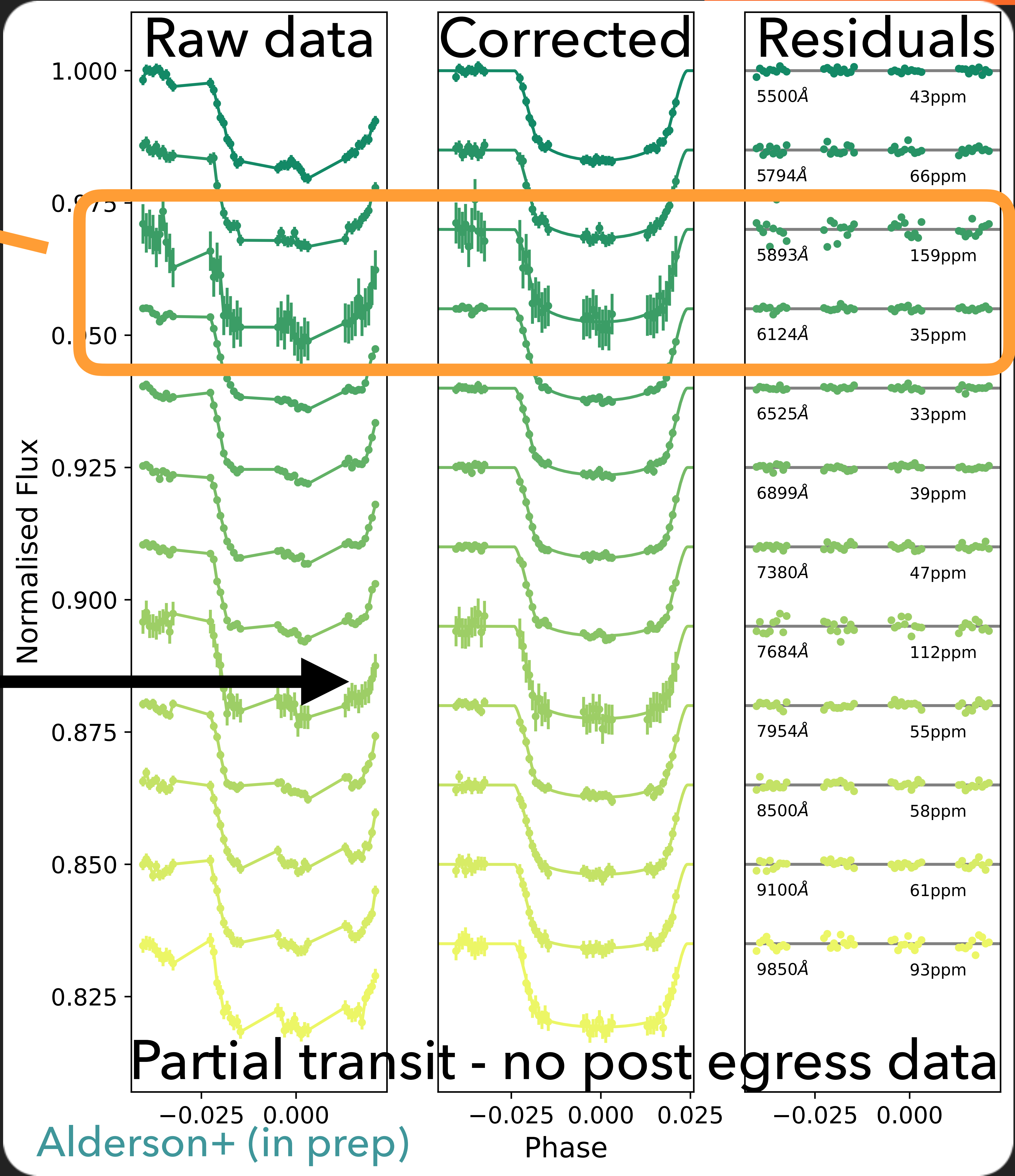
Iva Laginja, PhD Researcher, Laboratoire d'Astrophysique in Marseille

VISUALIZING YOUR RESULTS

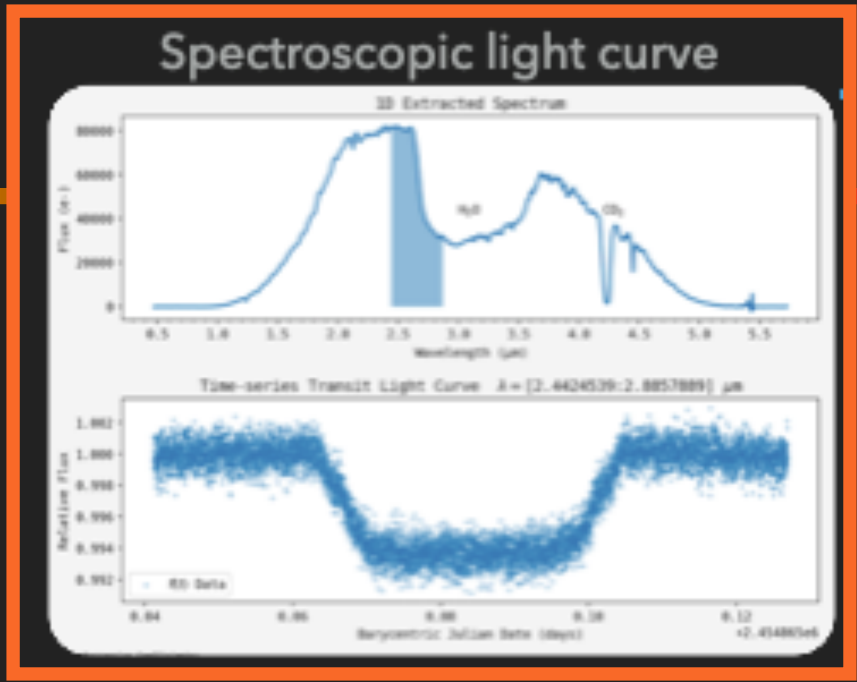




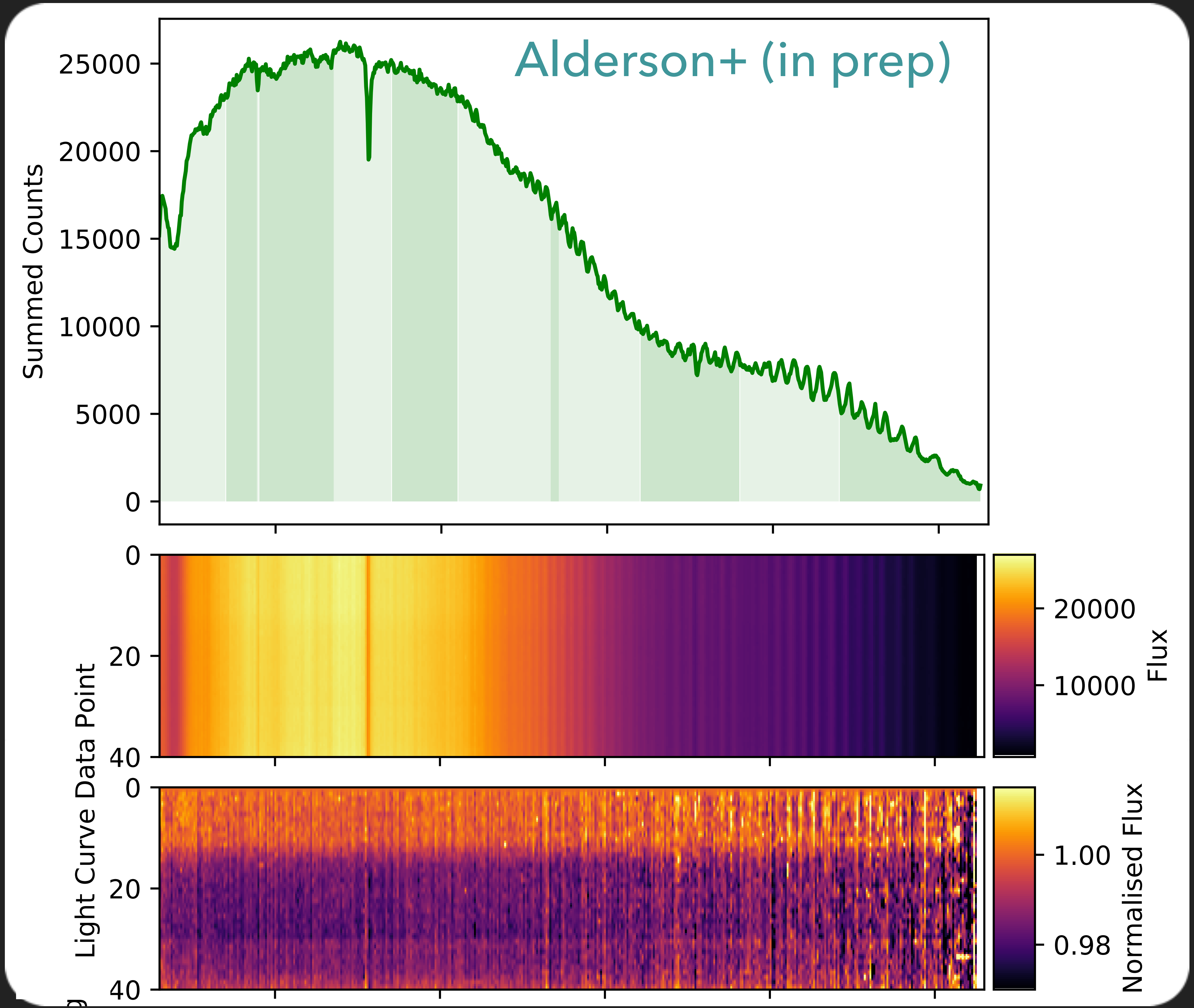
What is happening here?



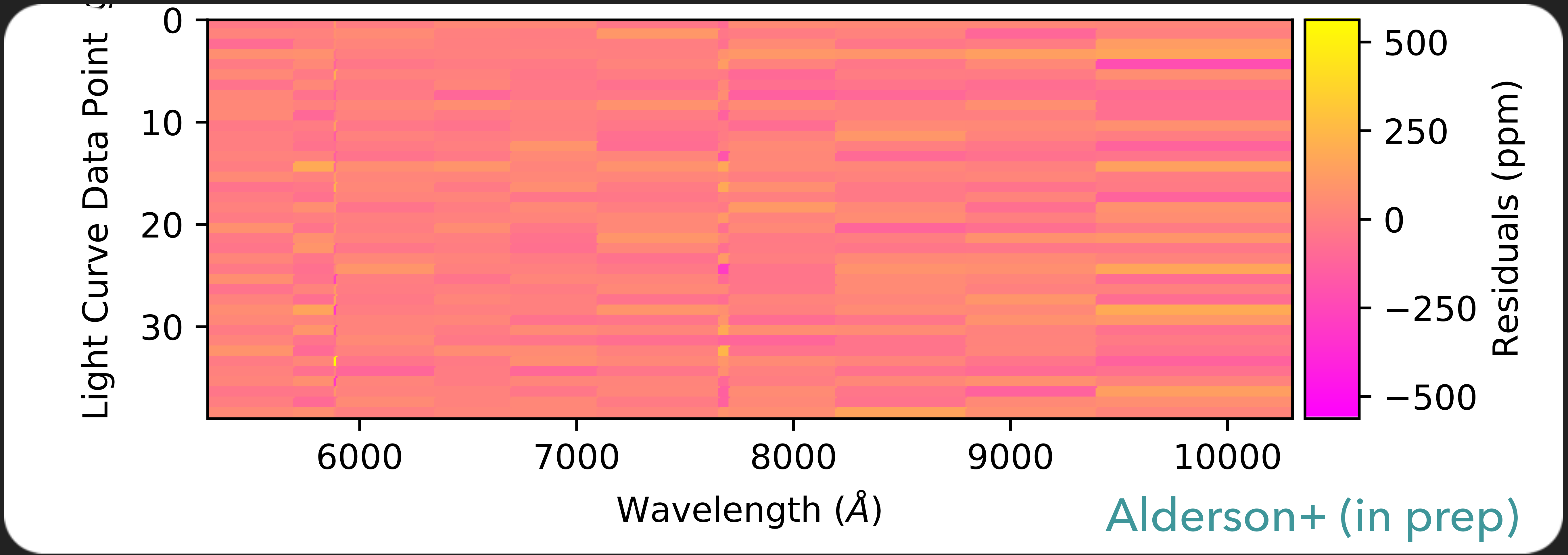
Lili Alderson, PhD Researcher, University of Bristol

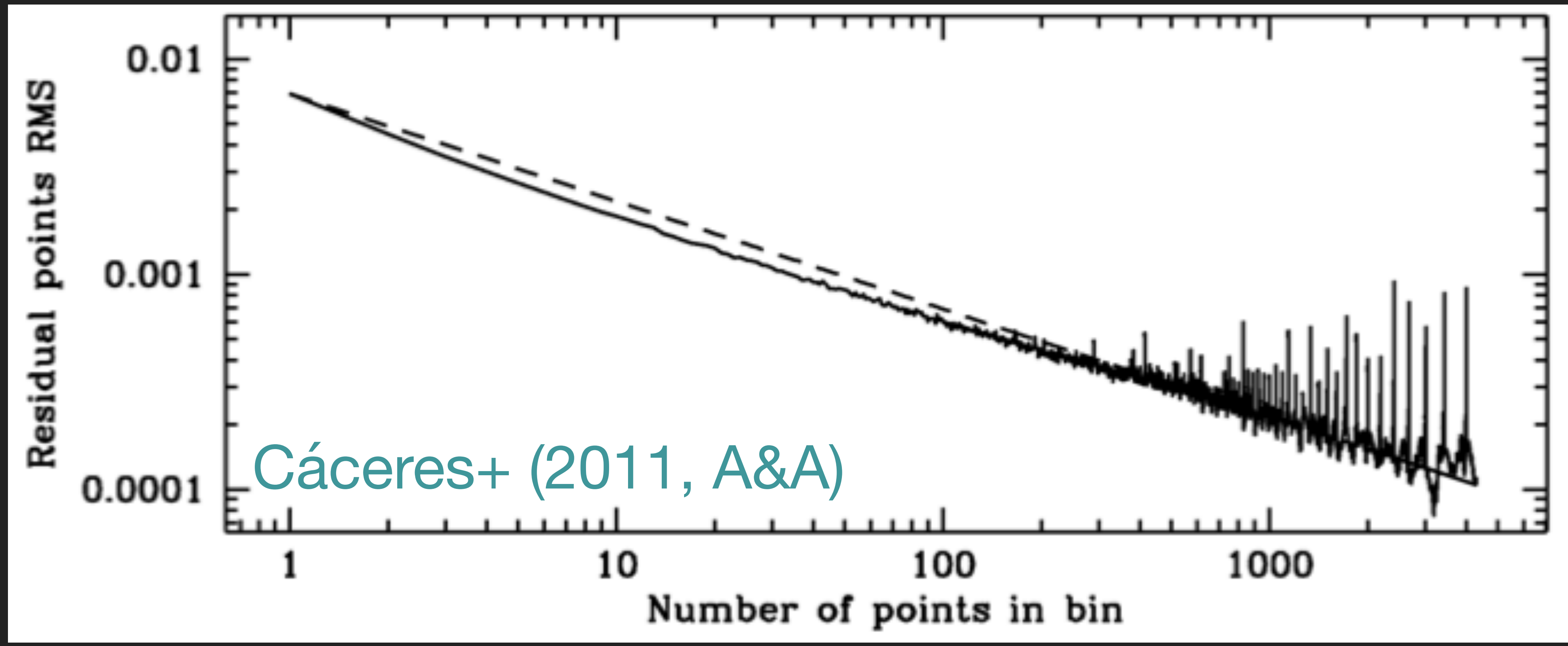


BINNING YOUR SPECTRUM



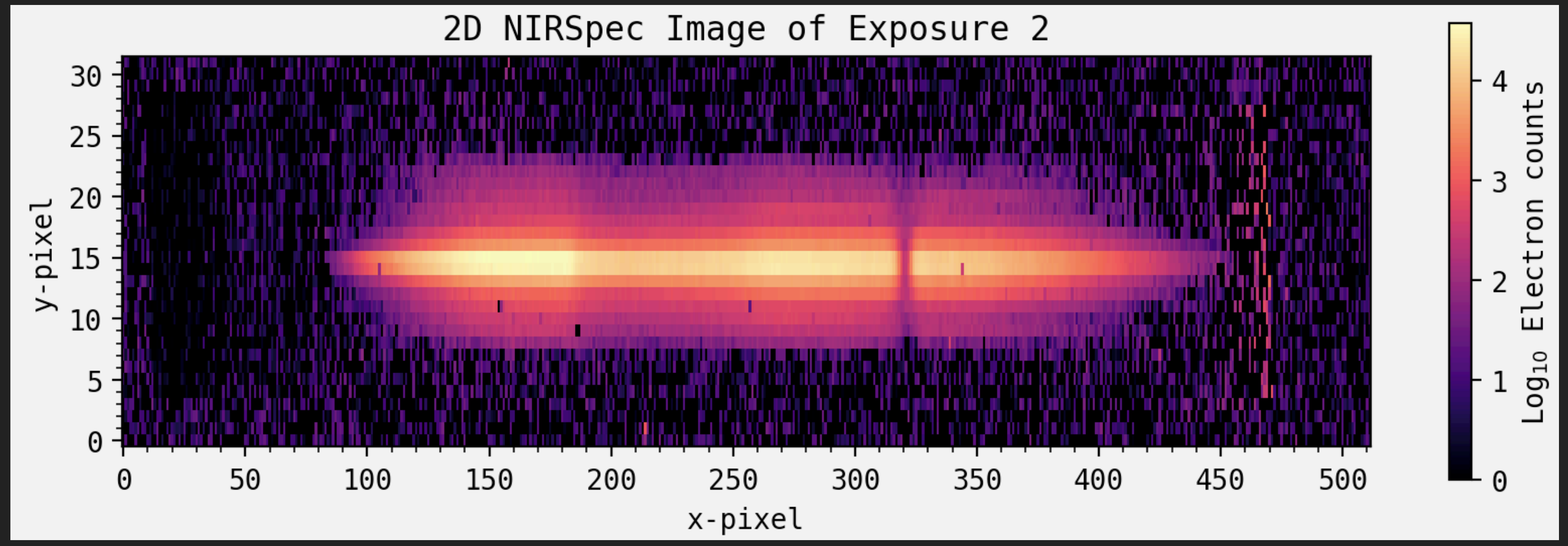
Pixel map of the light curve residuals (data - model) for each wavelength bin



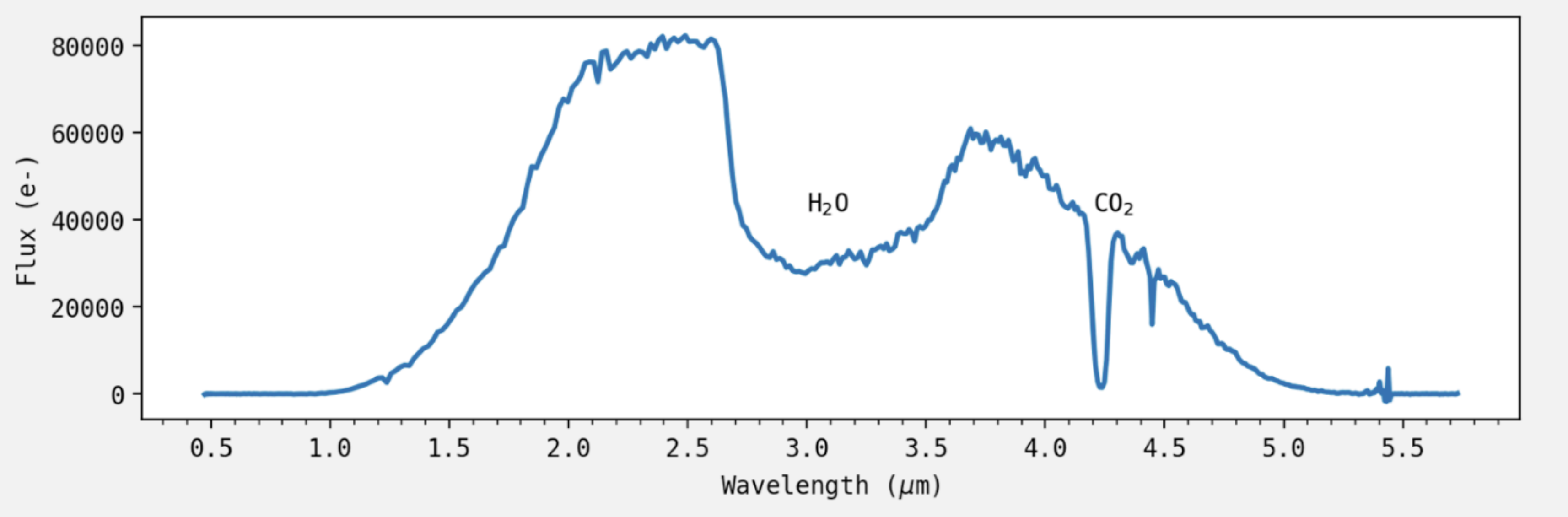


Lili Alderson,
PhD Researcher,
University of Bristol

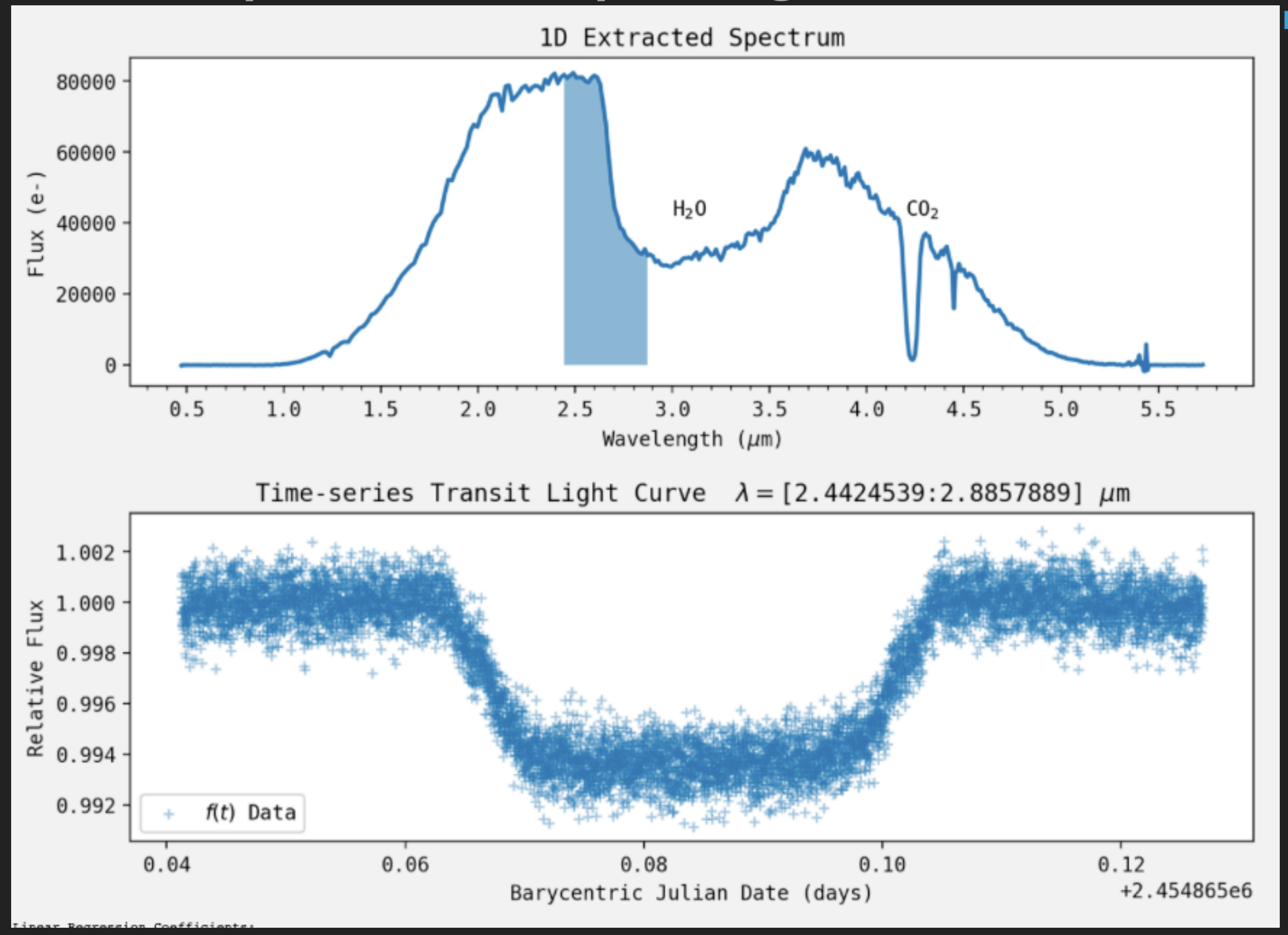
WHAT STEPS DO WE NEED TO LOOK AT?



From 2D images
to
1D stellar spectra

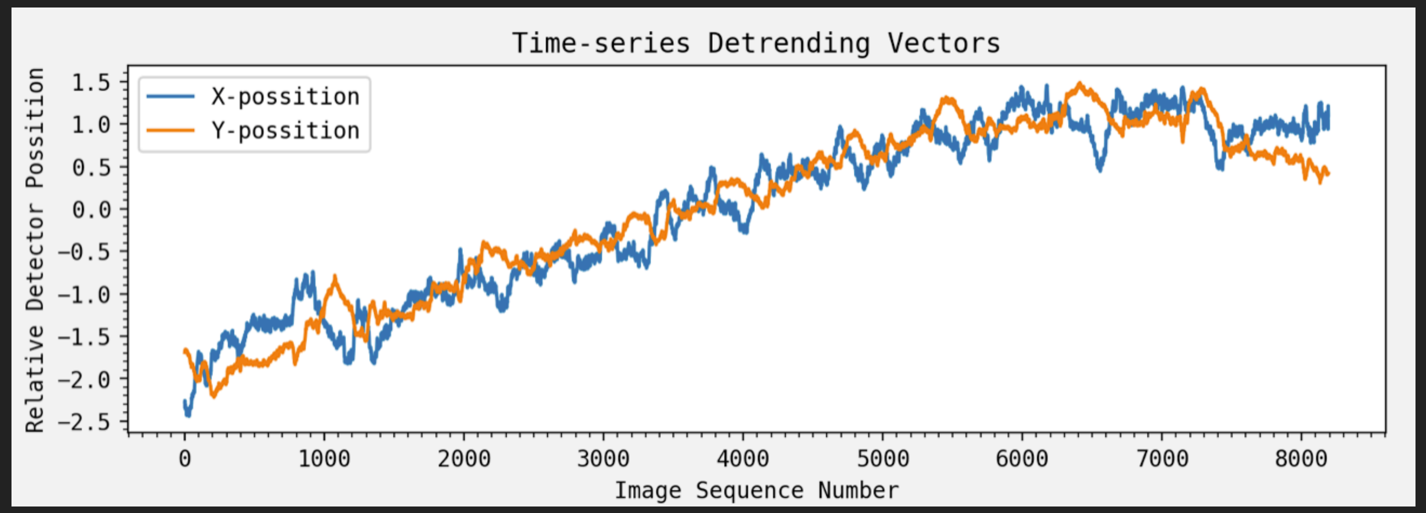


Spectroscopic light curve



+

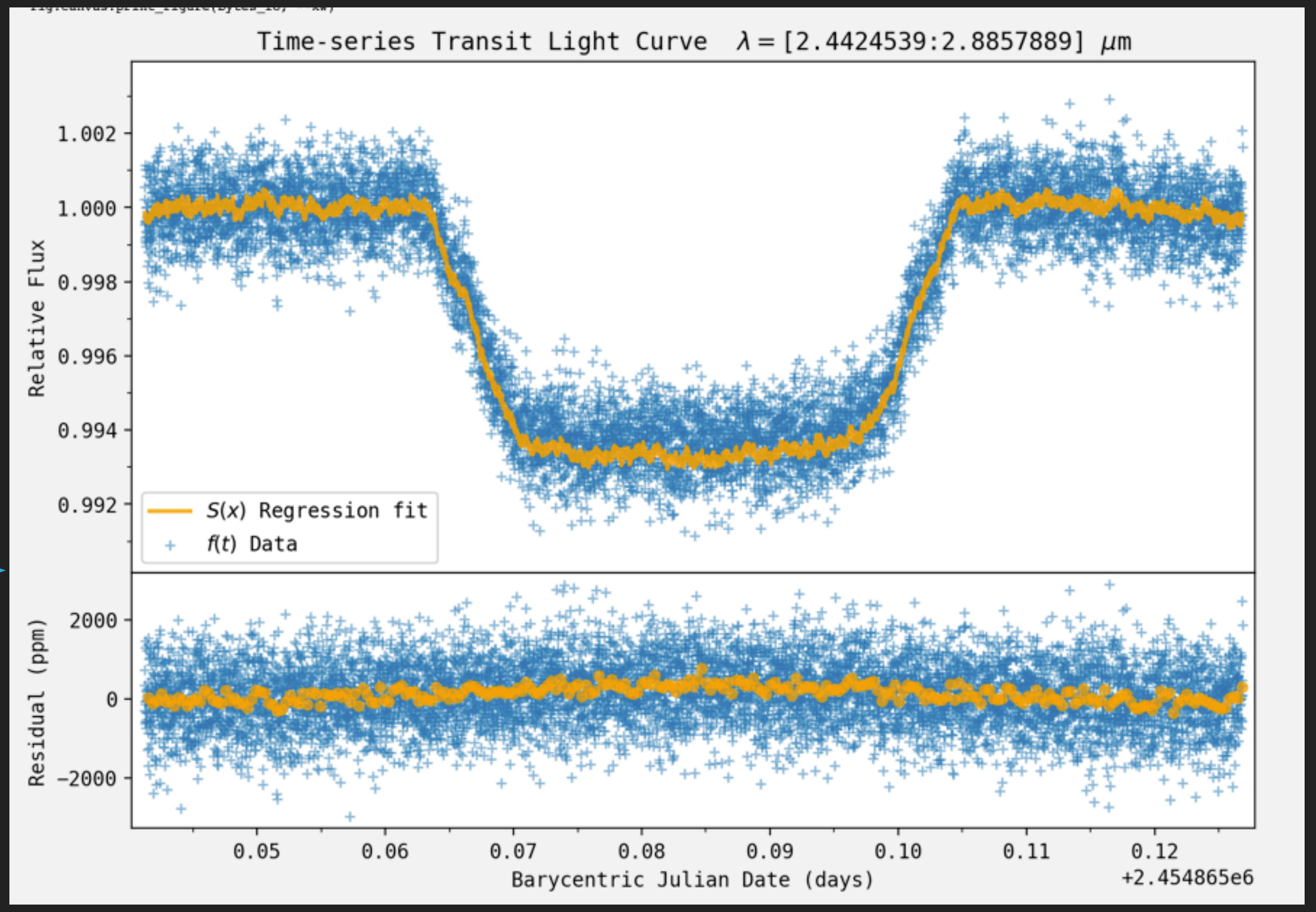
Detrending parameters



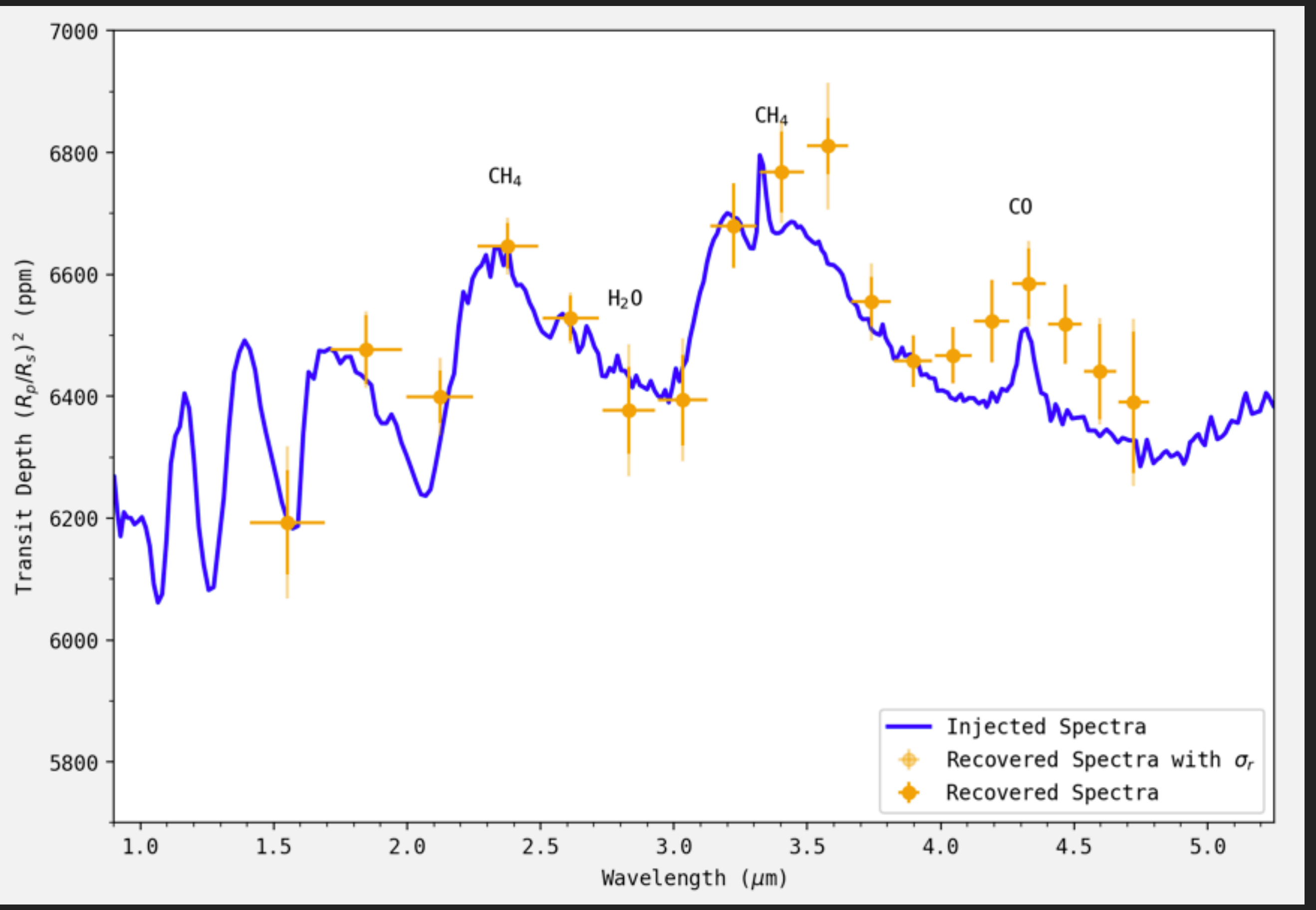
+

...

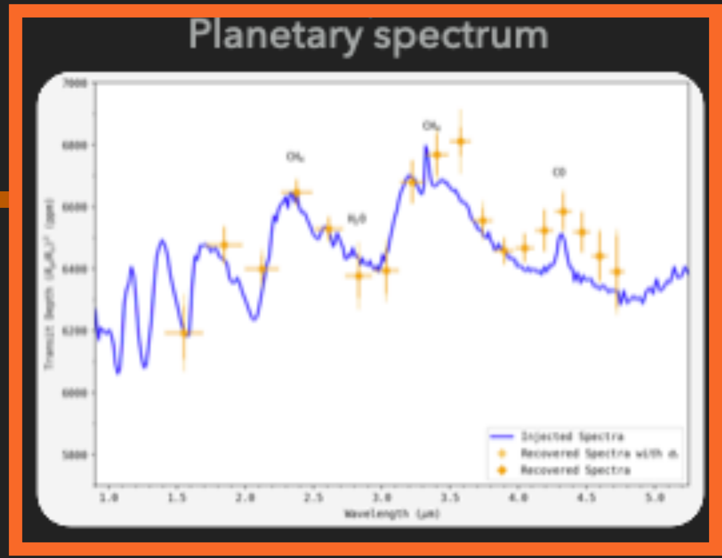
Fitted light curve



Planetary spectrum



Images from D.Sing NIRSpec reduction using ExoTiC-ISM functions - see https://spacetelescope.github.io/jdat_notebooks/notebooks/transit_spectroscopy_notebook/Exoplanet_Transmission_Spectra_JWST.html

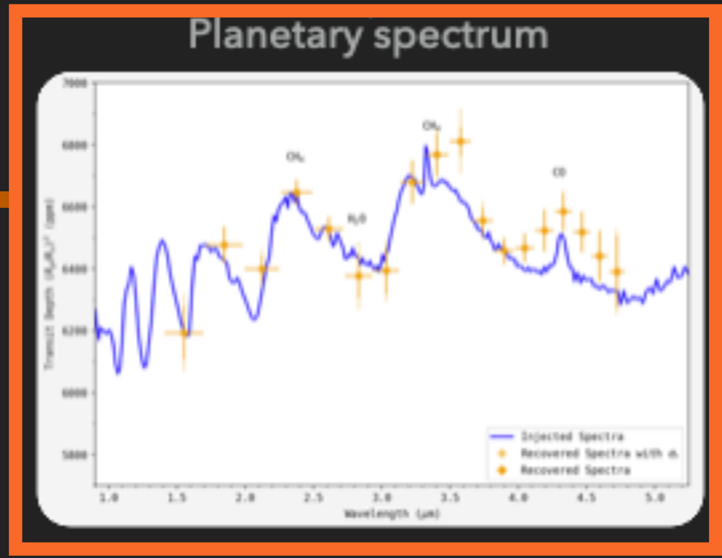


DIRECTLY COMPARING REDUCTION METHODS

It is equally as important to validate the shape of the transmission spectrum across multiple reductions.

If there is a feature there all of them should be able to find them.

Figures comparing the transmission spectra from various reduction techniques. In each of these examples the spectra were all well within 2σ of each other



COMPARING MULTIPLE VISITS AND INSTRUMENTS

It is important to determine if the spectra are consistent across multiple instruments and observations to combine multiple wavelengths.

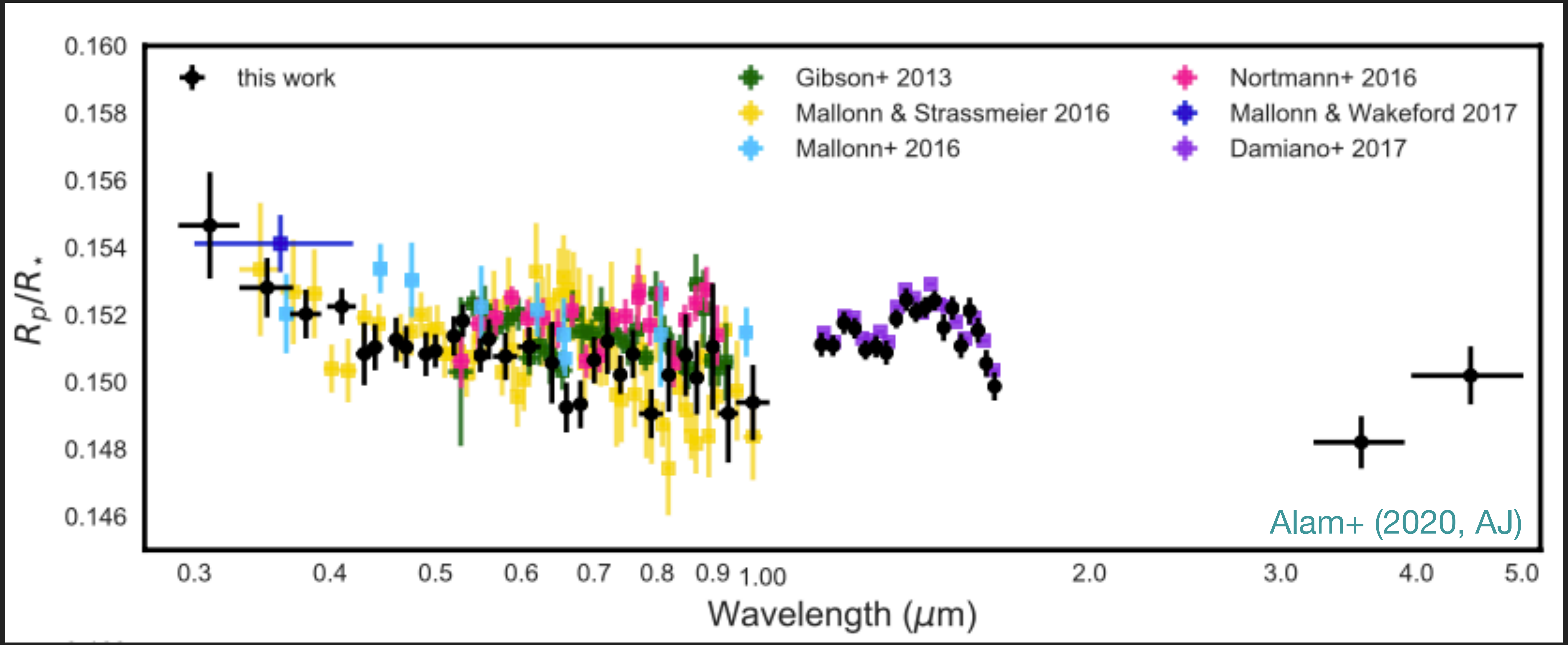


Figure showing the comparison across multiple instruments datasets and analysis

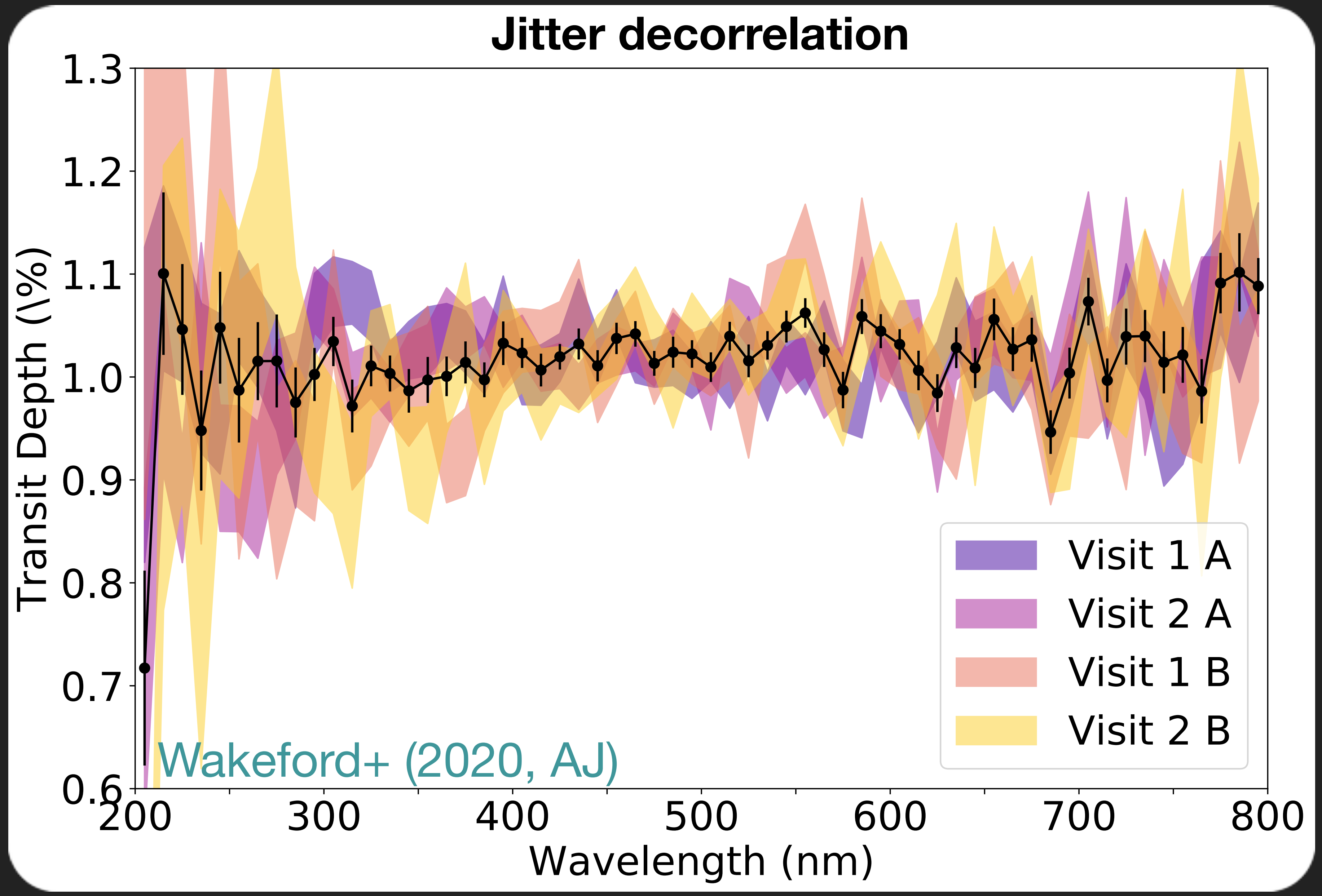
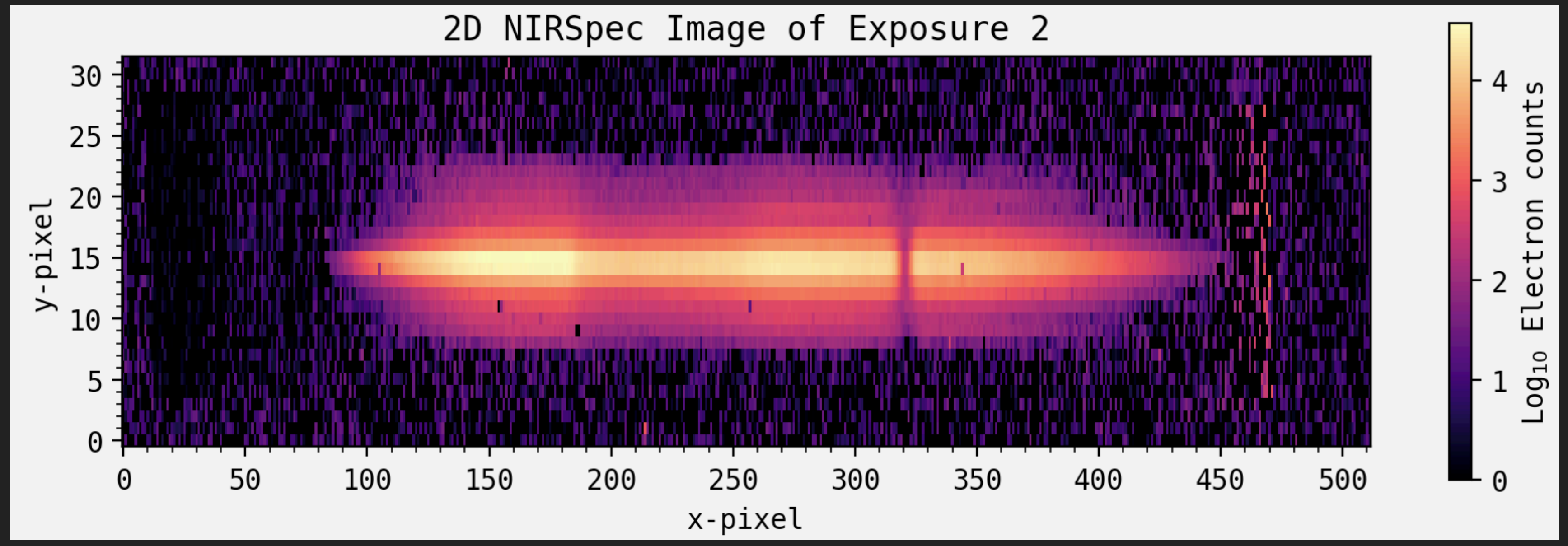


Figure showing the comparison across multiple observations with the same instrument and analysis

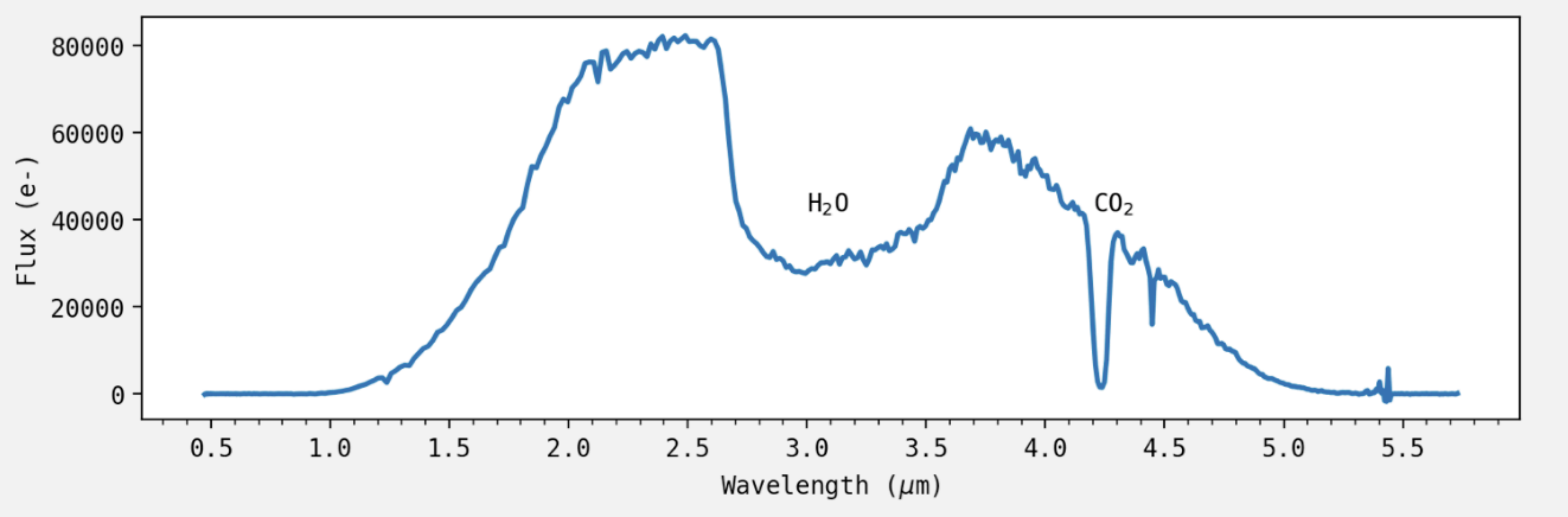
Is there enough information to determine a trend linked to 3D or 4D effects?

(See Kilpatrick+ 2020, AJ)

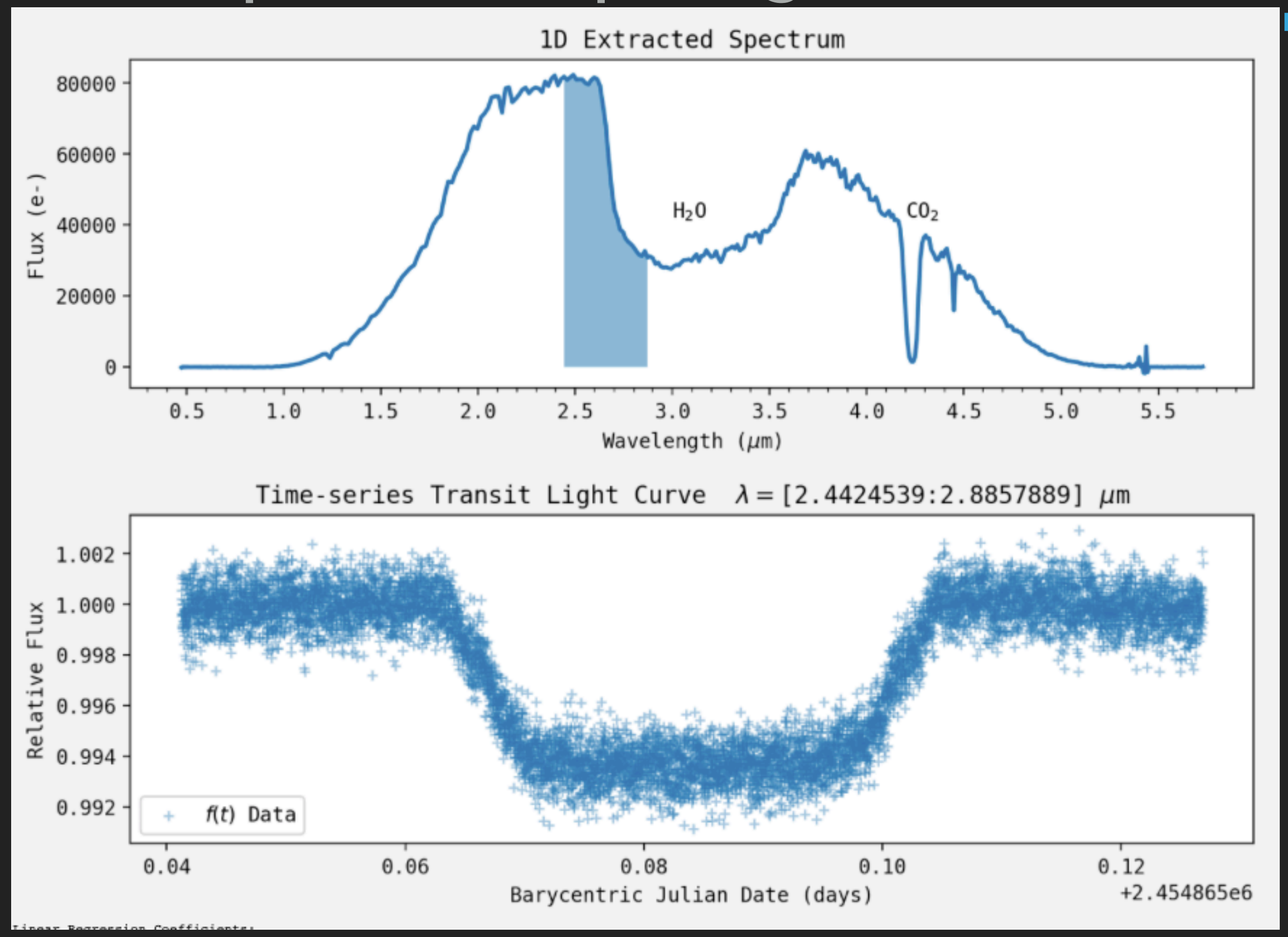
WHAT STEPS DO WE NEED TO LOOK AT?



From 2D images
to
1D stellar spectra

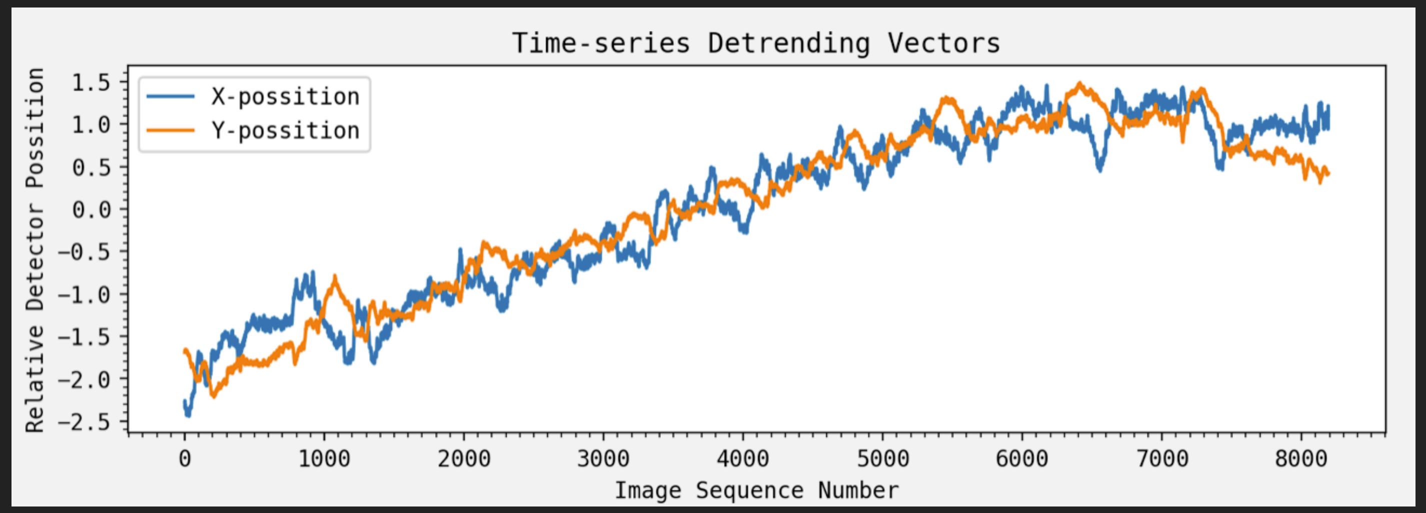


Spectroscopic light curve



\+

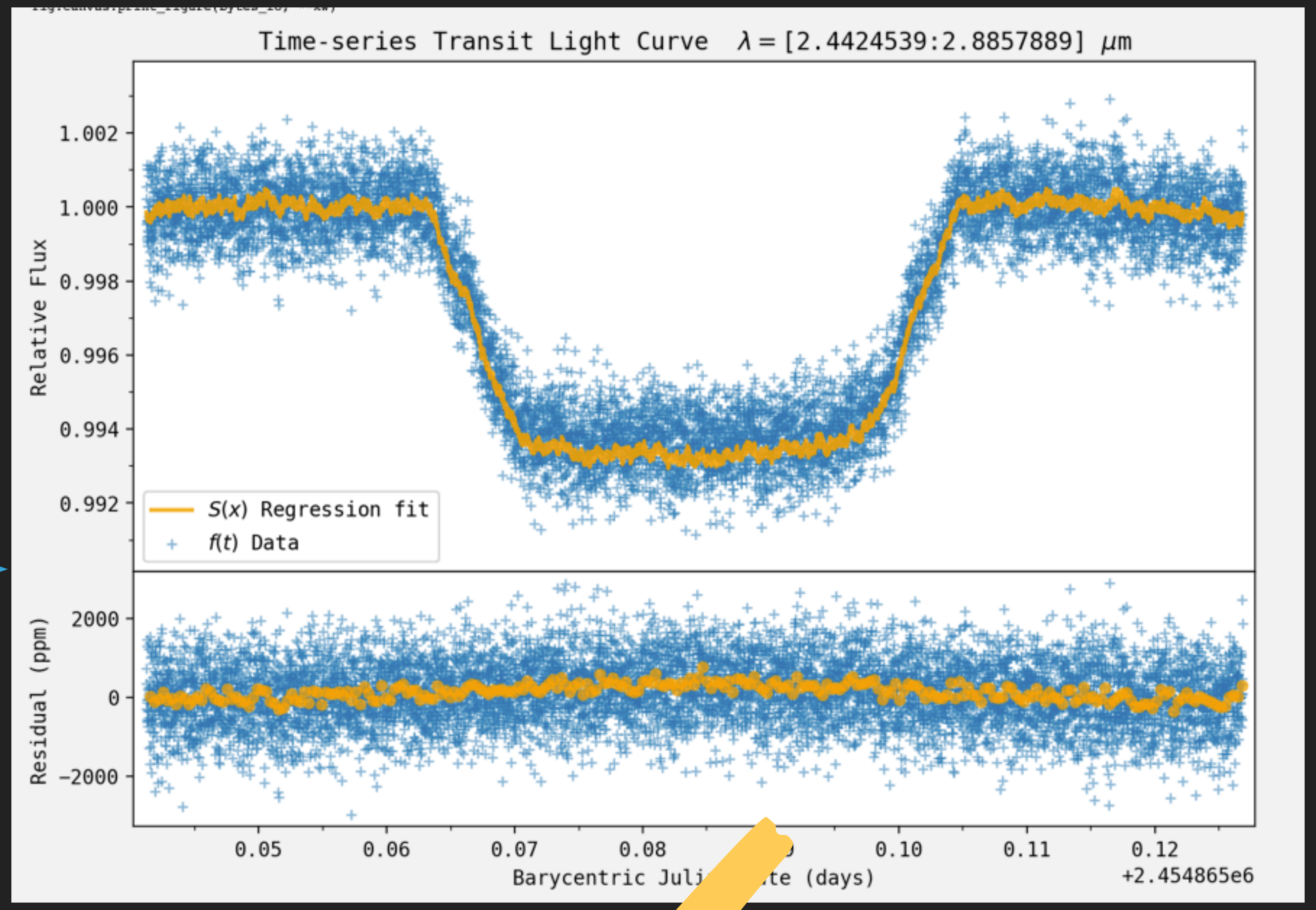
Detrending parameters



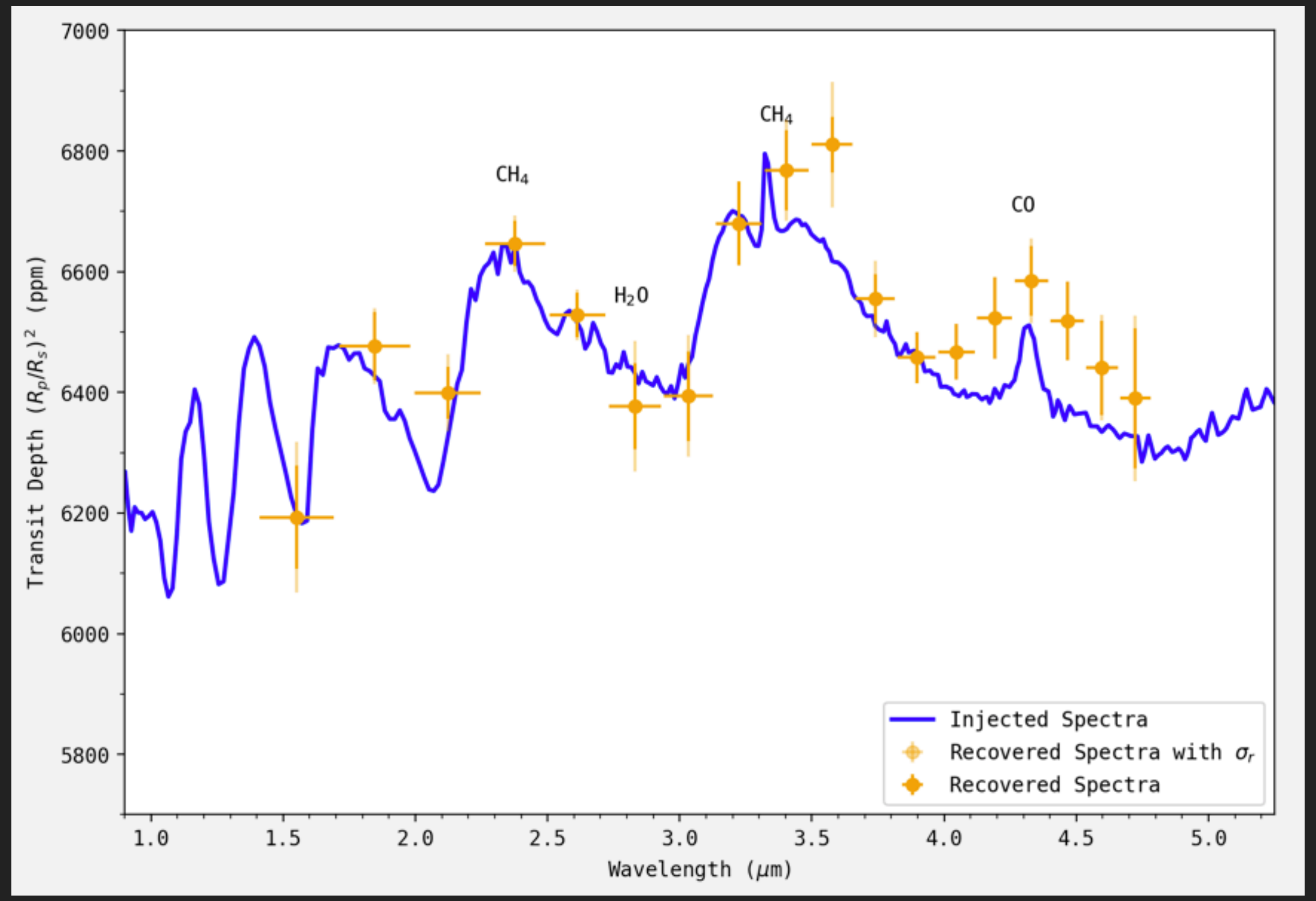
\+

...

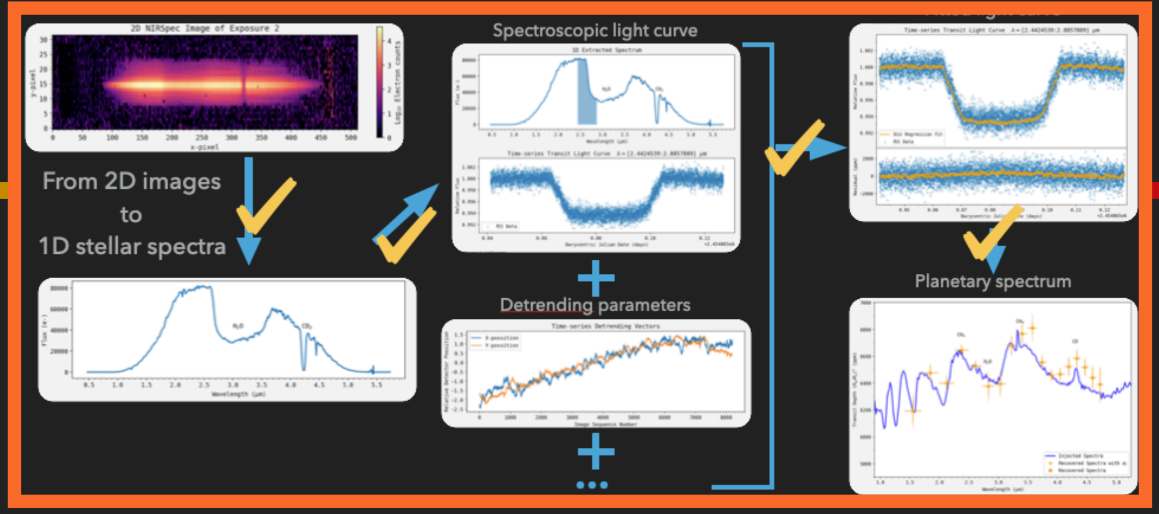
Fitted light curve



Planetary spectrum



Images from D.Sing NIRSpec reduction using ExoTiC-ISM functions - see https://spacetelescope.github.io/jdat_notebooks/notebooks/transit_spectroscopy_notebook/Exoplanet_Transmission_Spectra_JWST.html



OUR JOB AS OBSERVERS

We need to be as consistent, complex, complete, and timely as possible in our analysis (please pick two)

Test the limits of the instrument (DD-ERS)

Model the systematics and PSF as a function of time and accurately adapt the analysis techniques to account for any changes

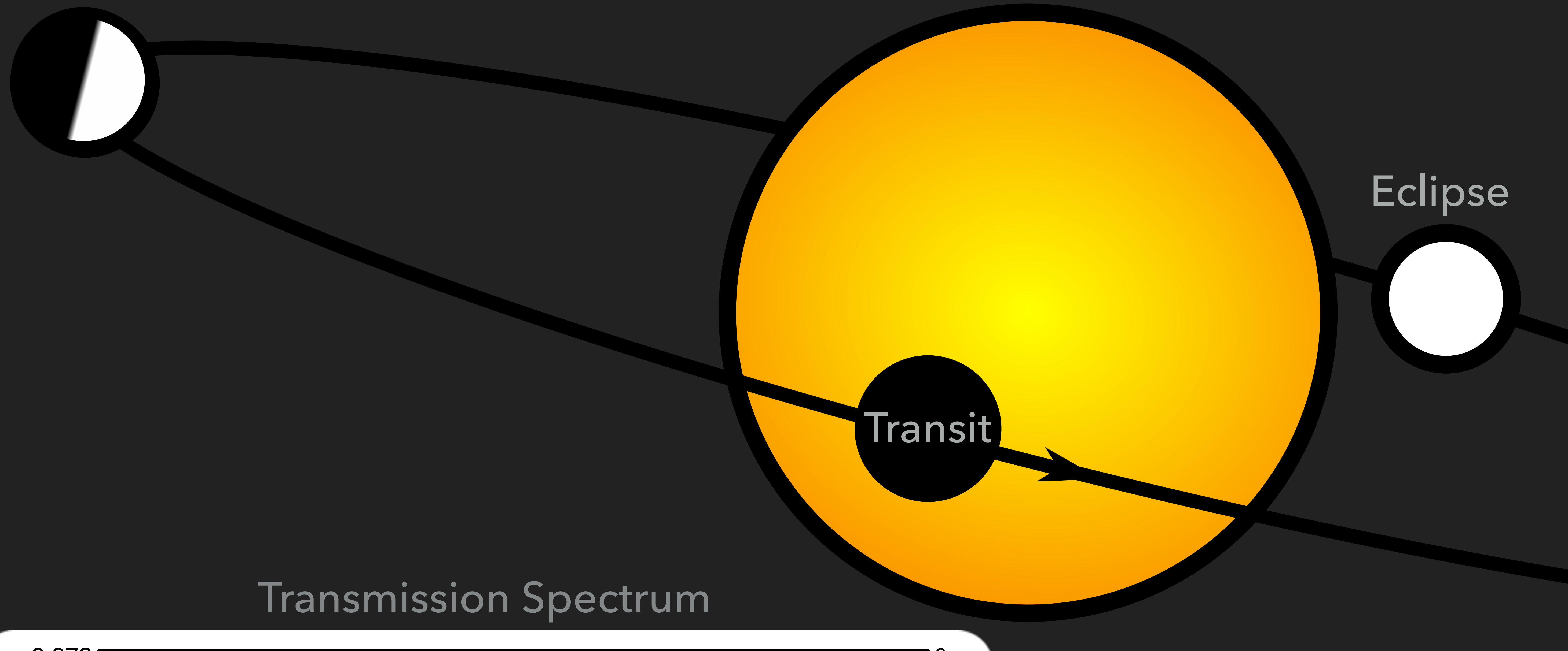
Determine if there are offsets between combined datasets or analysis methods

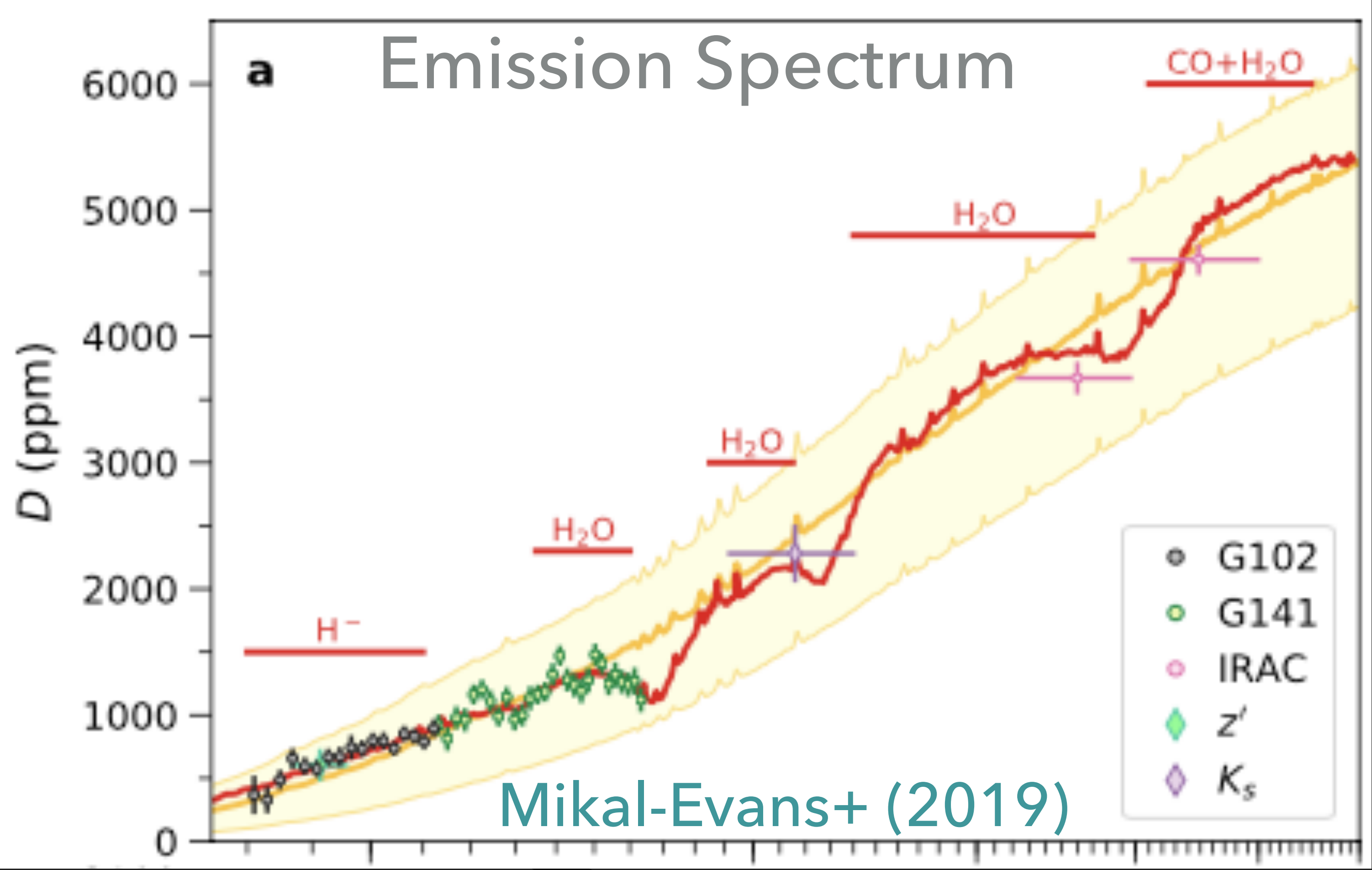
Learn from observations:

- the physical reasons for the dominant systematics
- how to make the next observations more precise

Explain the origins of the data uncertainty and discuss the impact that may have on retrieved abundances

NEXT! KEVIN STEVENSON WITH THE BREAKDOWN





Transmission Spectrum