



The SHERLOCK PIPELINE

A Python pipeline to explore
space-based observations in
the search for exoplanets

Francisco J. Pozuelos
(IAA-CSIC)



OUTLINE

(I) General overview

- How to search for planets in photometric data?
- TESS mission
- Why SHERLOCK?

(II) The SHERLOCK workflow and scientific cases

- The six SHERLOCK modules
- Examples of scientific cases: SPECULOOS & FATE projects

(III) Examples

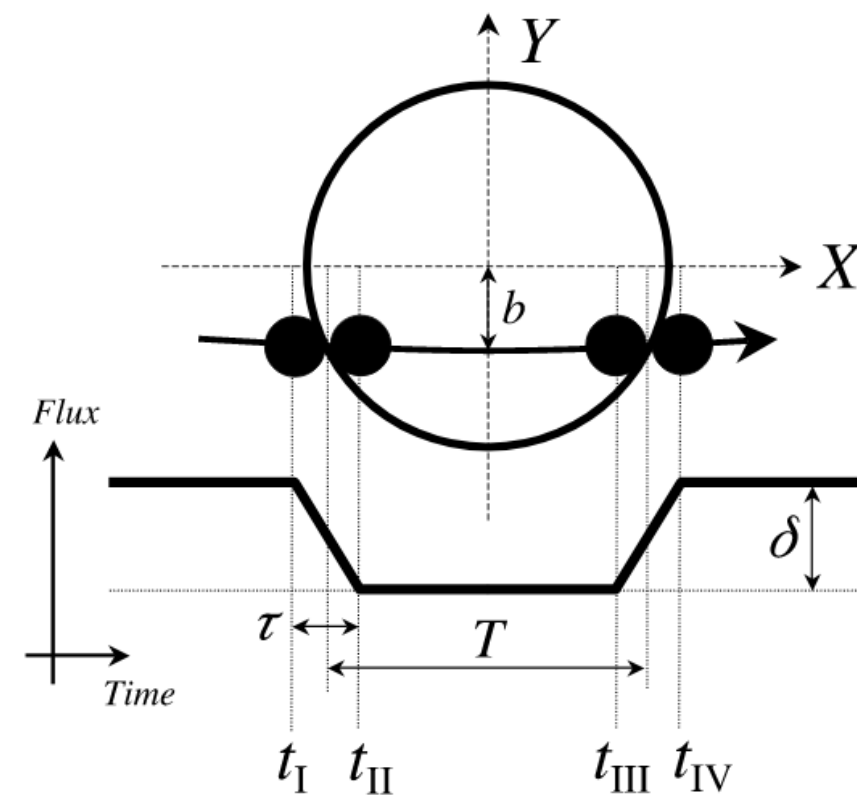
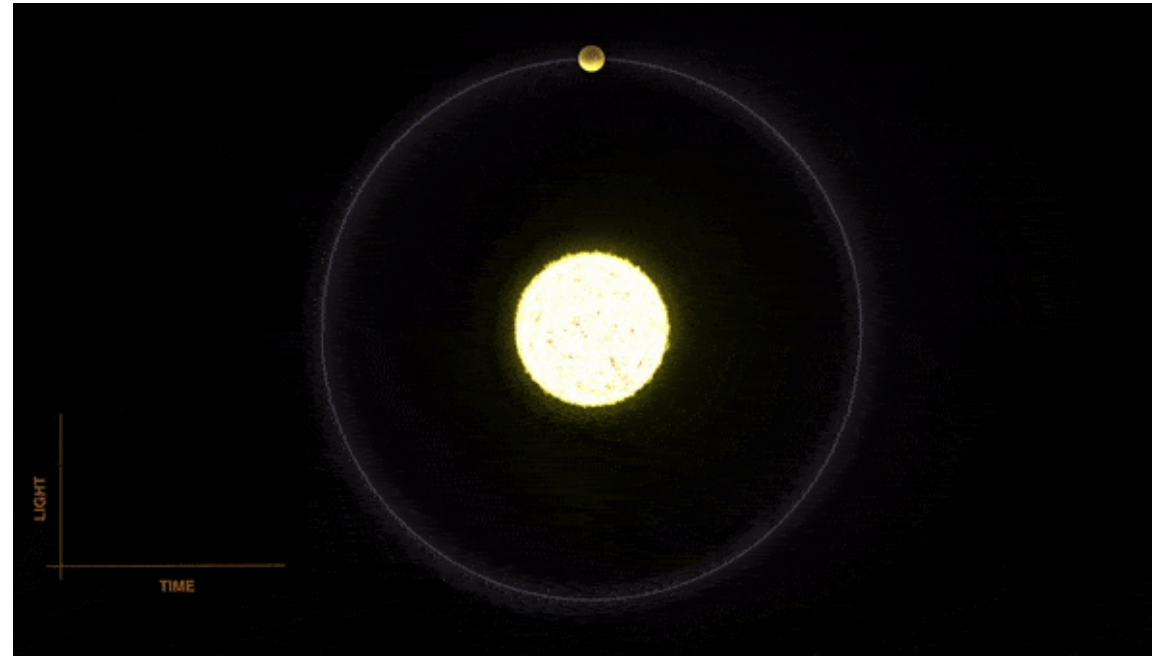
- Jupyter Notebooks
- A fast rotator: TOI-540
- A multiplanetary system: TOI-270
- A false positive: TOI-5747

(I) General overview

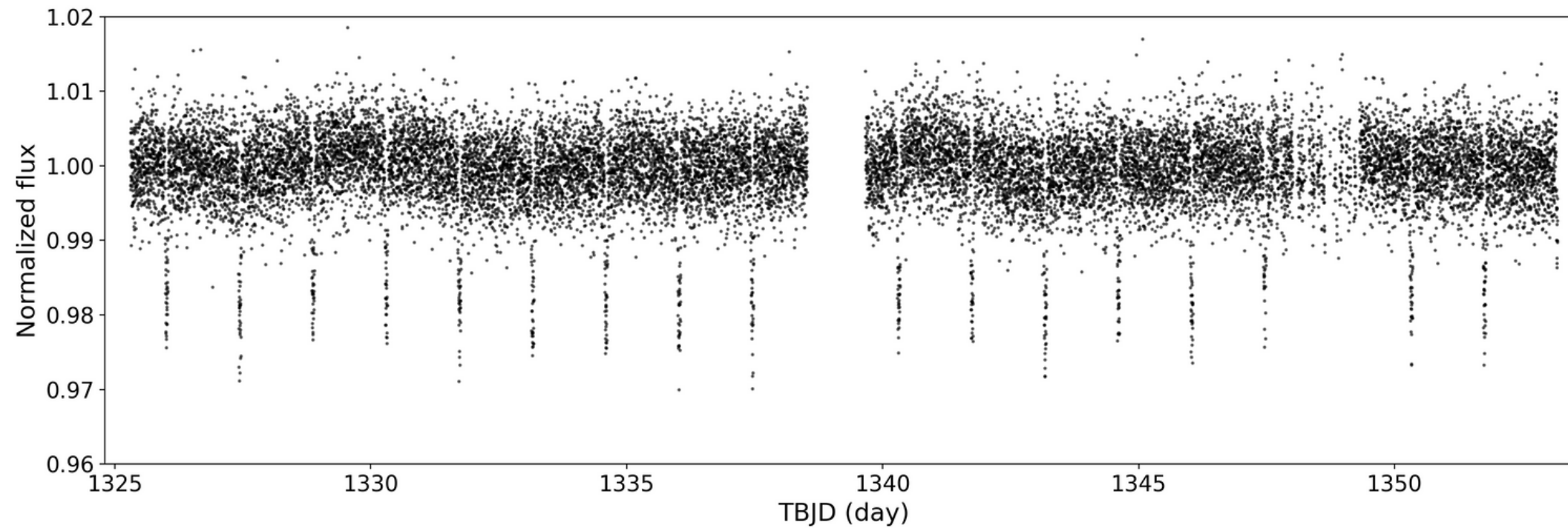
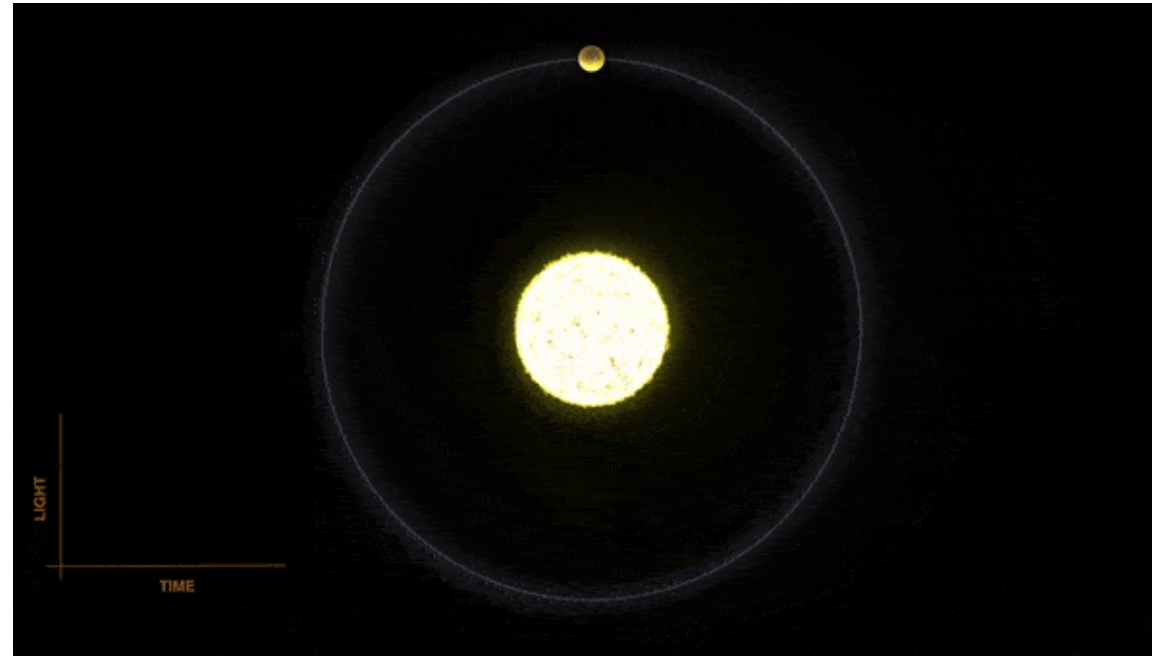
- How to search for planets in photometric data?
- TESS mission
- Why SHERLOCK?



How to search for planets in photometric data?

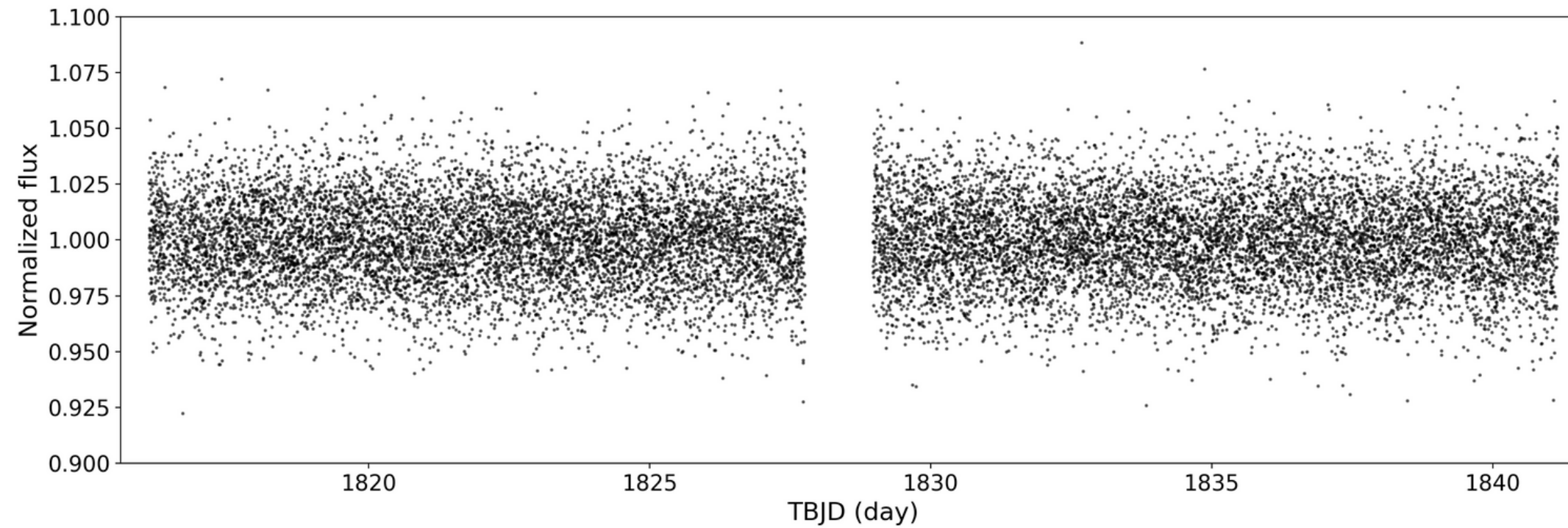
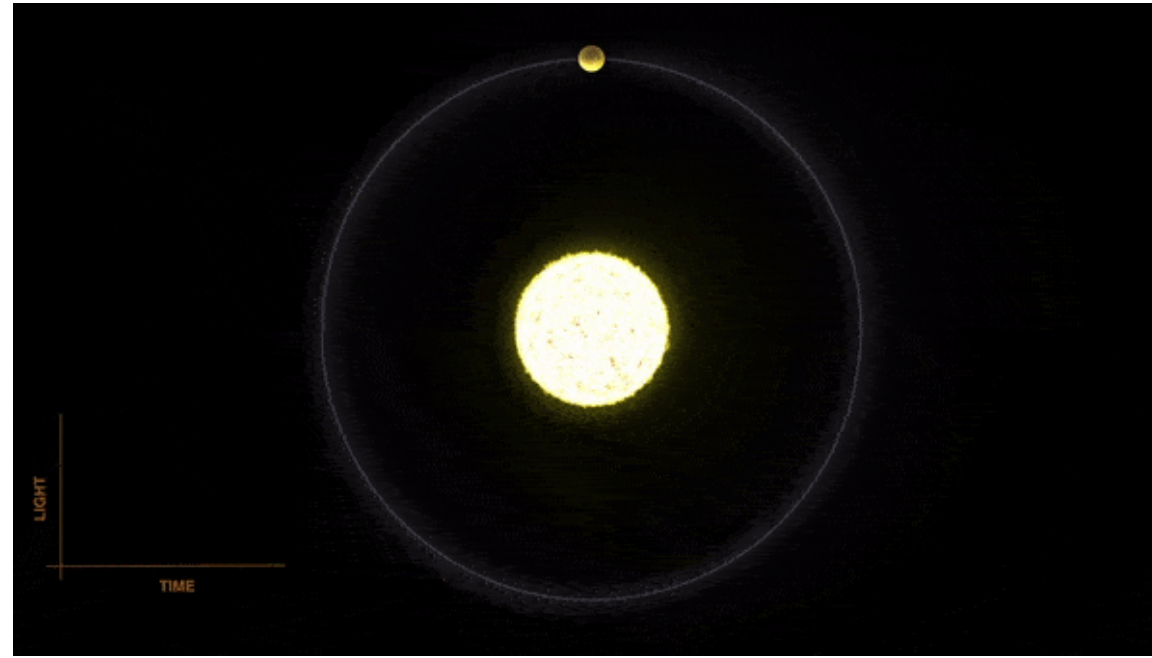


How to search for planets in photometric data?



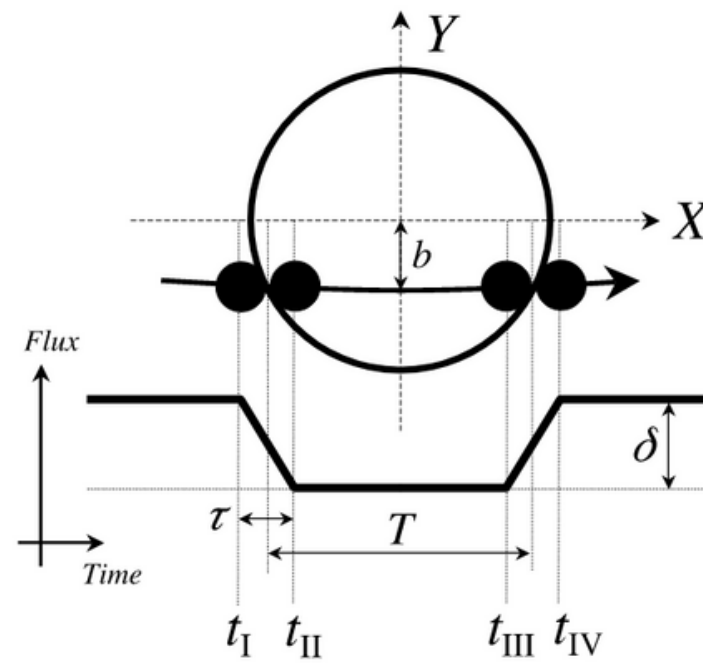
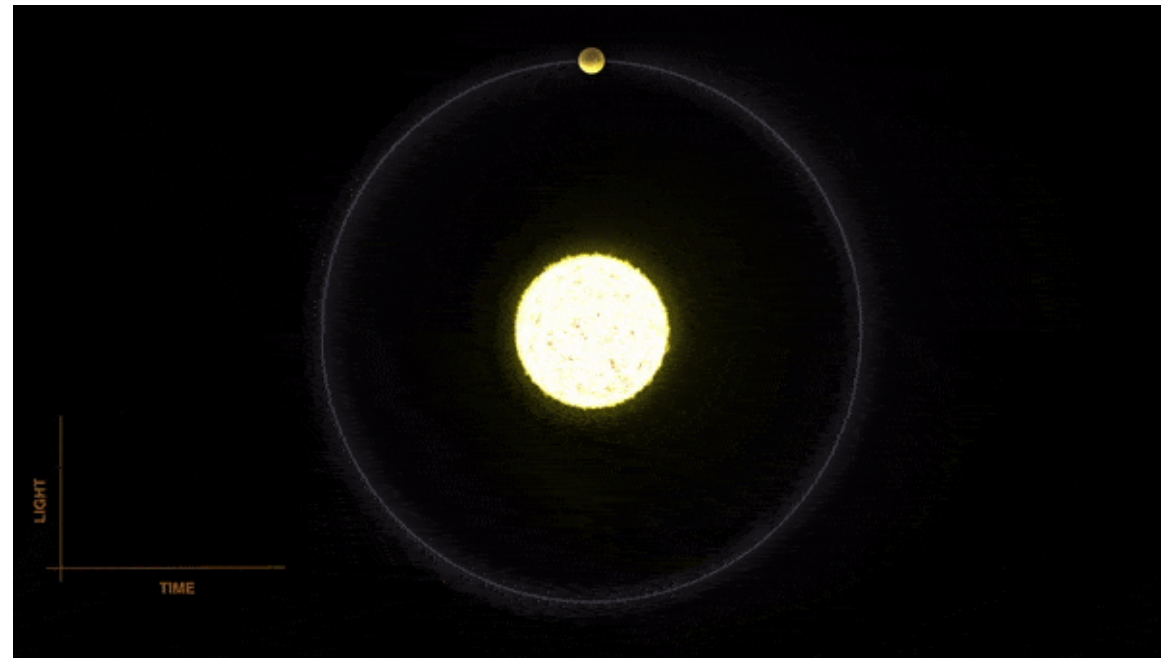
TOI	Period (days)	Radius (R_{\oplus})
101.01	1.43	13.25

How to search for planets in photometric data?



TOI	Period (days)	Radius (R_{\oplus})
1696.01	2.501	3.171

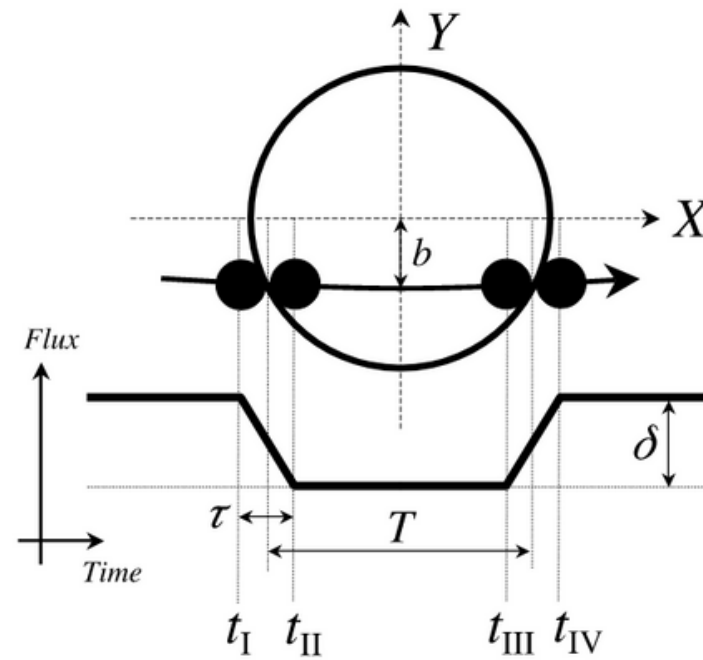
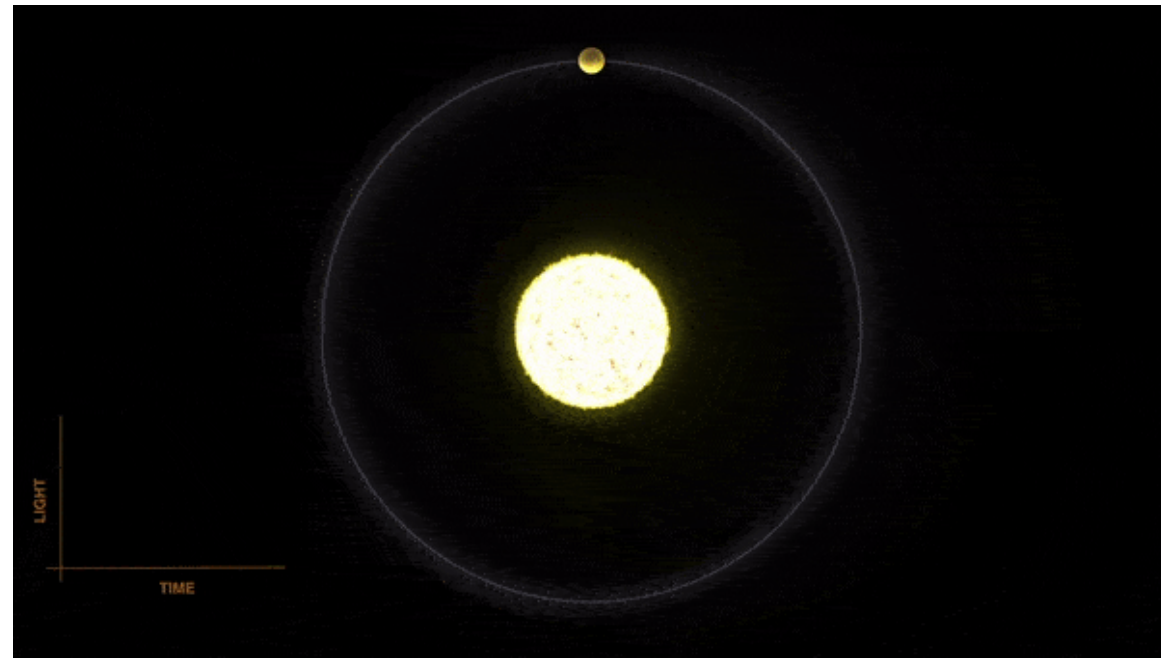
How to search for planets in photometric data?



Template transits using a range of:

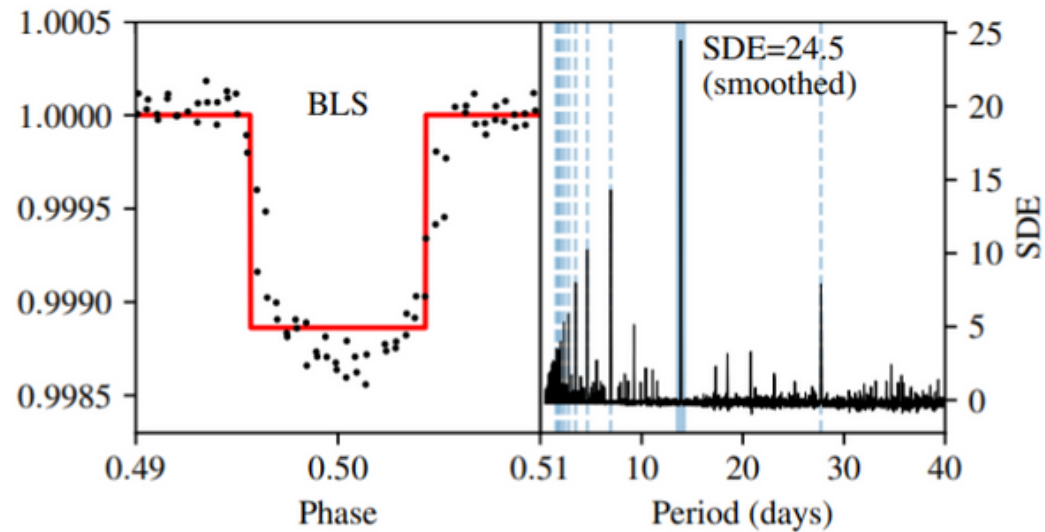
- periods
- depths
- durations

How to search for planets in photometric data?



Template transits using a range of:

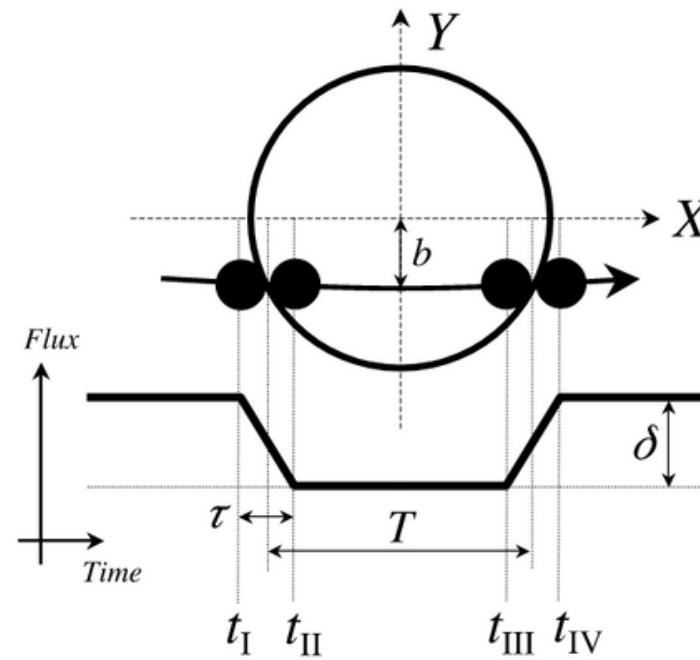
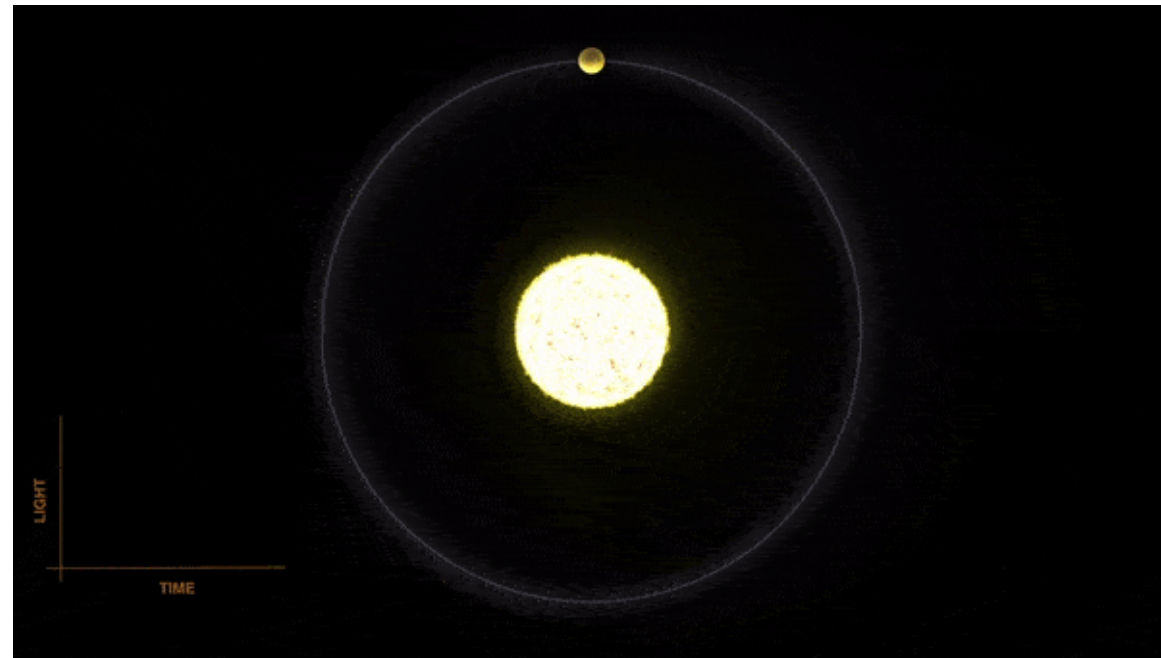
- periods
- depths
- durations



Box Least Squares

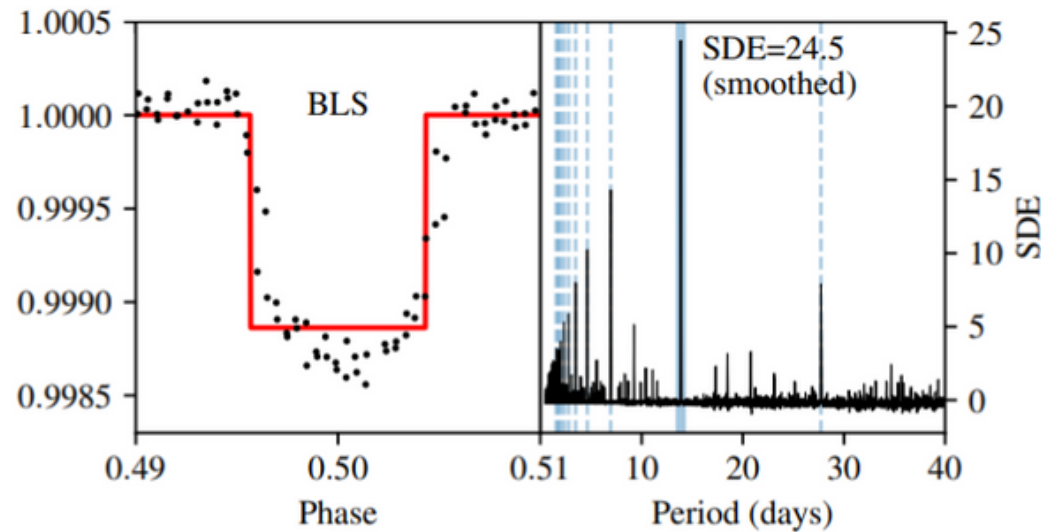
(Kovacs et al. 2002)

How to search for planets in photometric data?



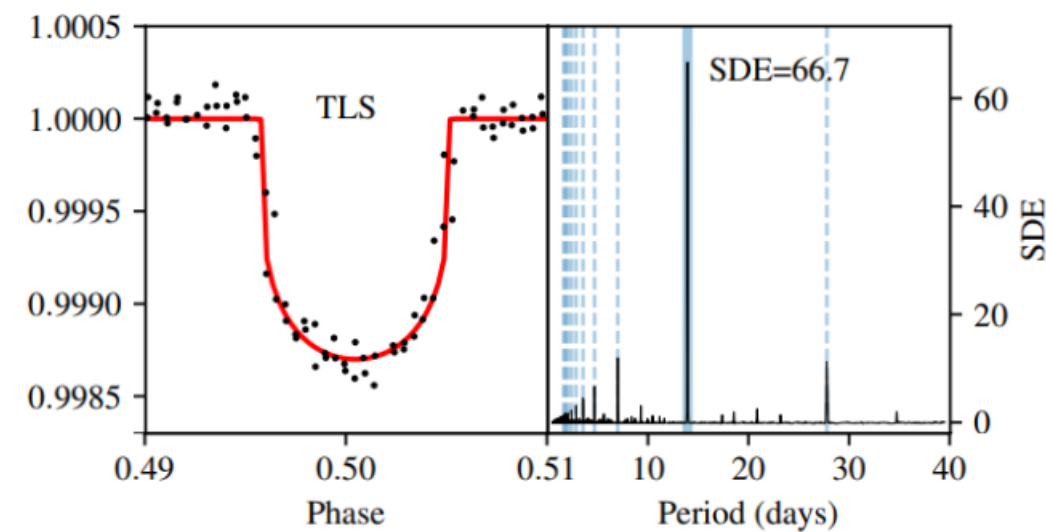
Template transits using a range of:

- periods
- depths
- durations



Box Least Squares

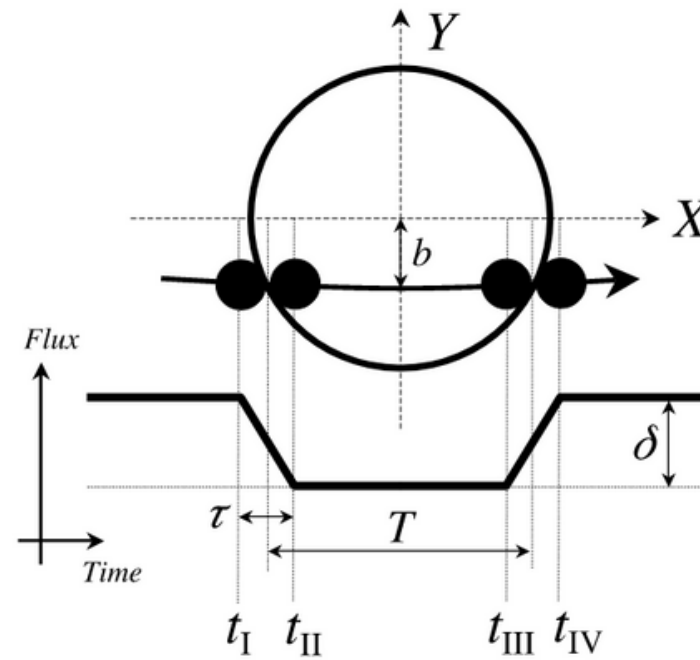
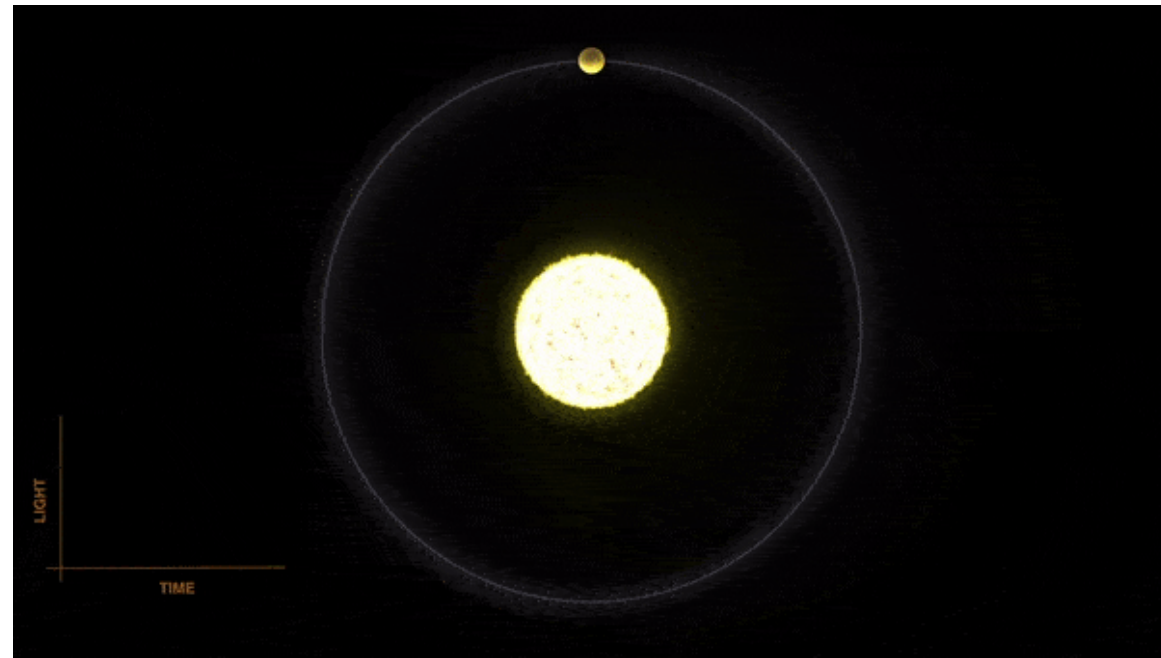
(Kovacs et al. 2002)



Transit Least Squares

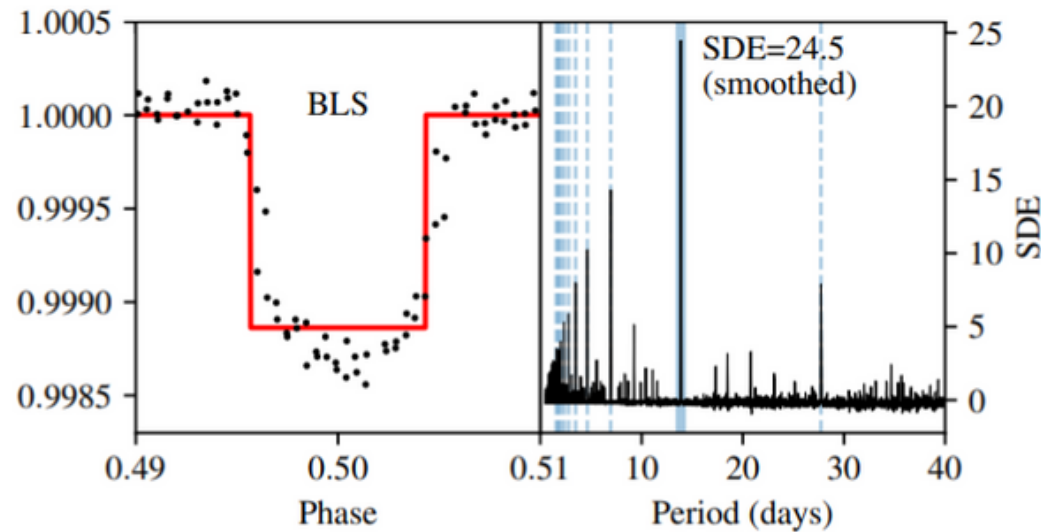
(Hippke et al. 2019)

How to search for planets in photometric data?

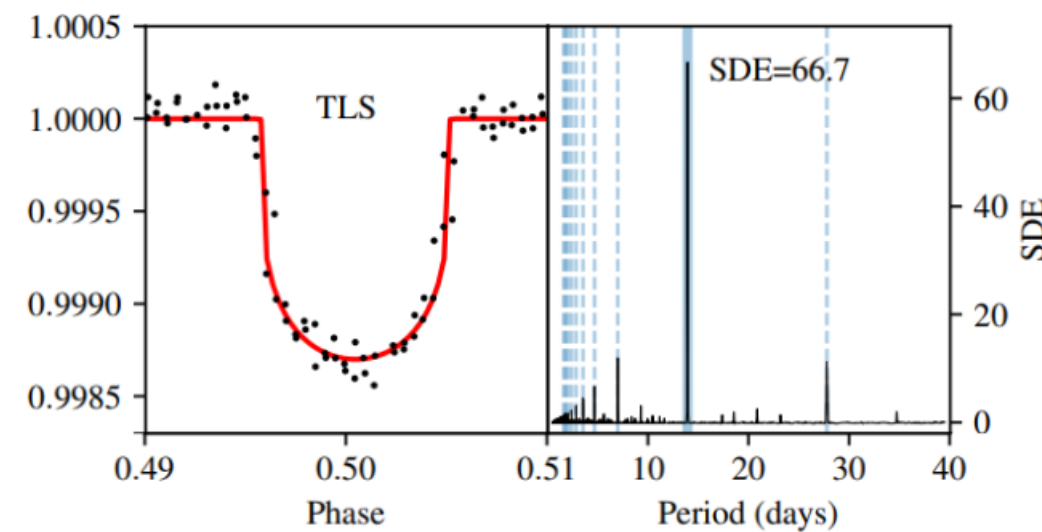


Template transits using a range of:

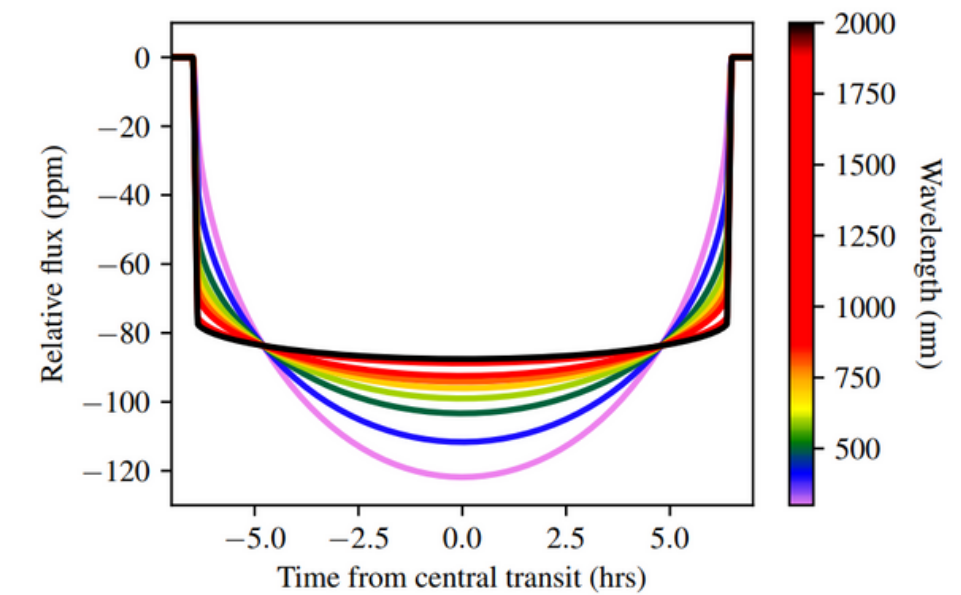
- periods
- depths
- durations



Box Least Squares
(Kovacs et al. 2002)



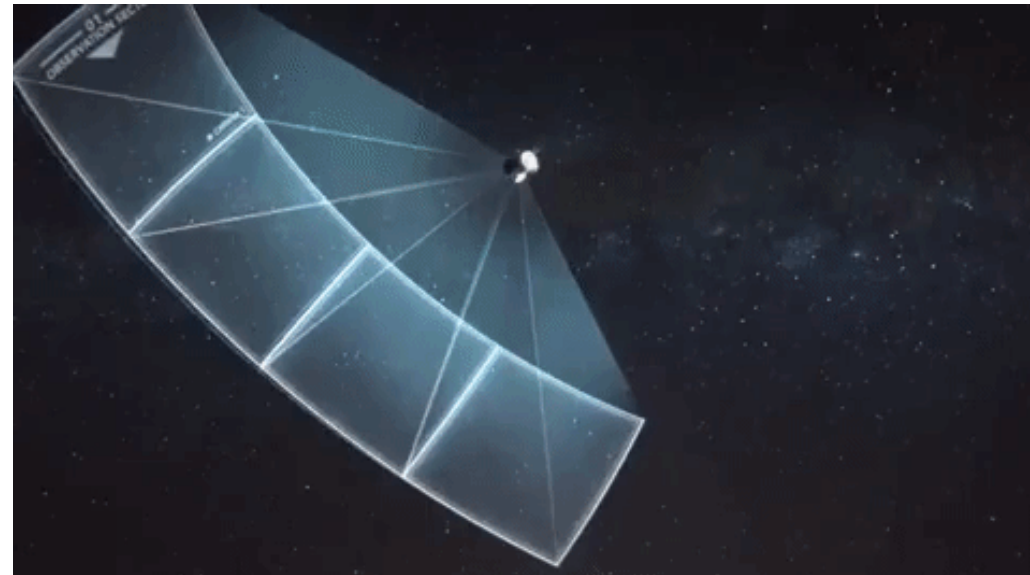
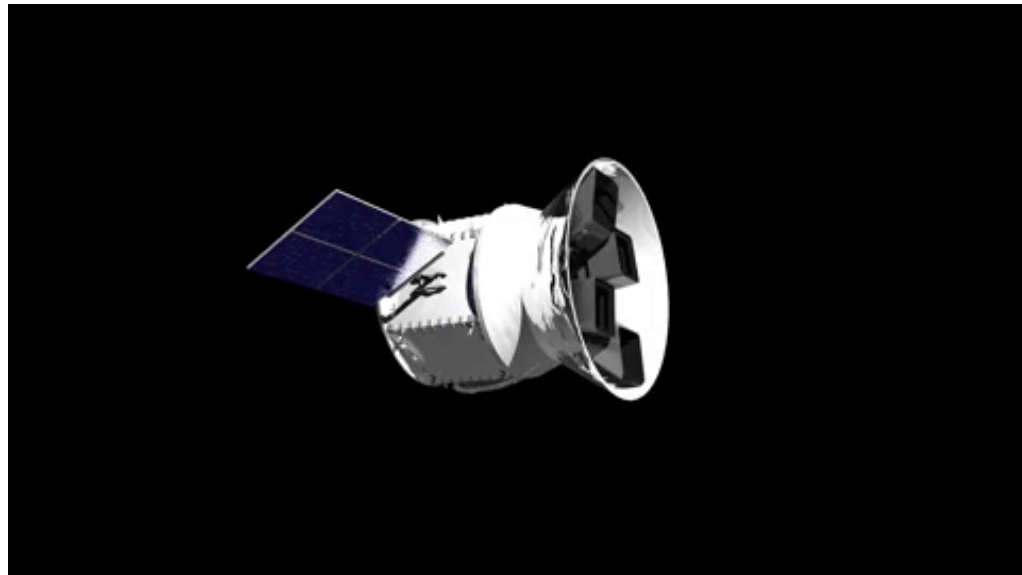
Transit Least Squares
(Hippeke et al. 2019)



Modulate the transit shape according to the stellar properties

TESS mission

- **Primary goal:** discovery of 50 L1-planets ($1-4 R_{\oplus}$, nearby, bright stars)
- Almost a **full sky survey** (80%)
- Now in the **extended mission** until 2024 (at least!)
- **Cadences:** 20s, 120s, 600s, 1800s
- **SPOC & QLP** (*Jenkins et al. 2016; Huang et al. 2020*)



TESS mission

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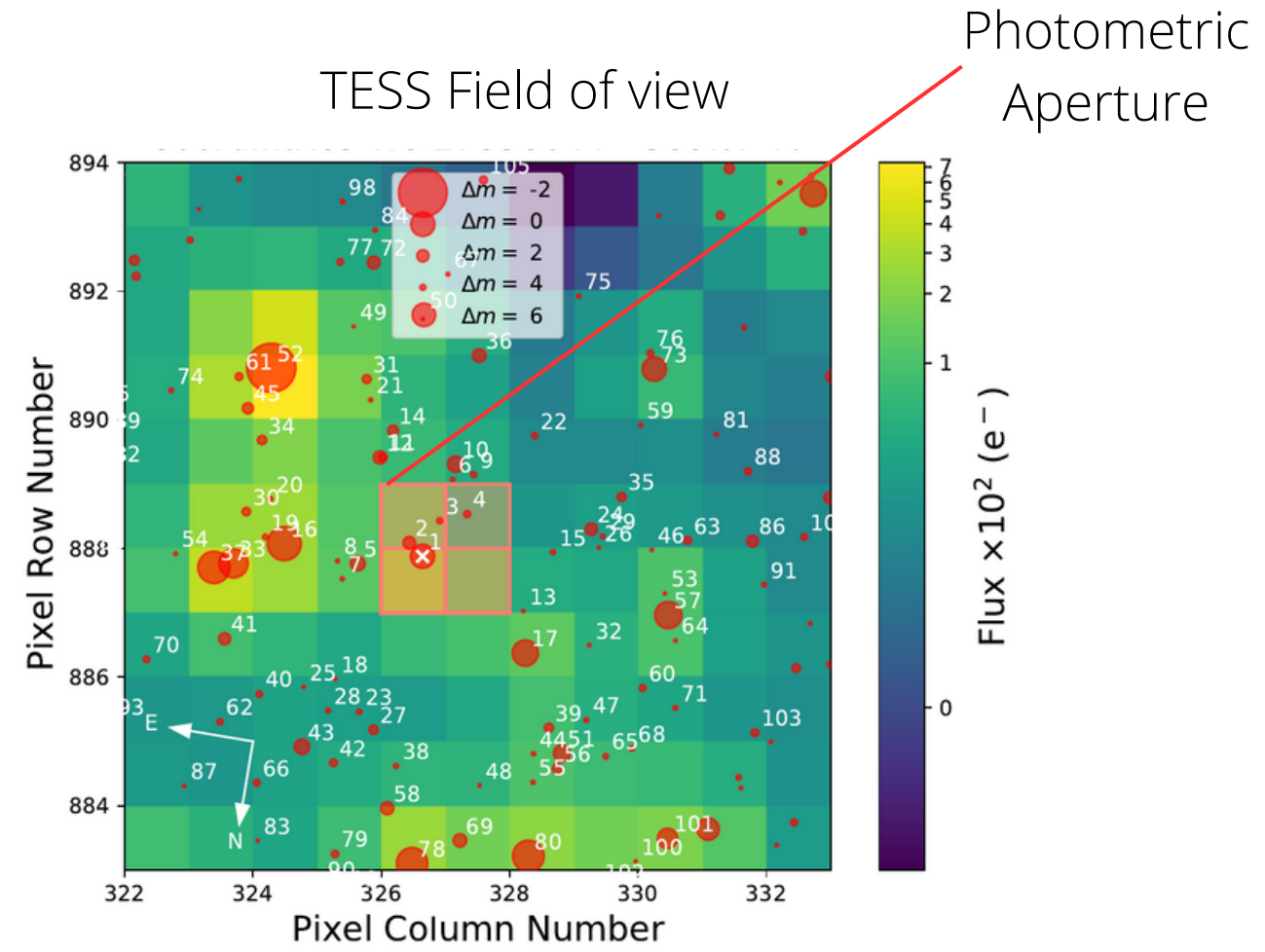
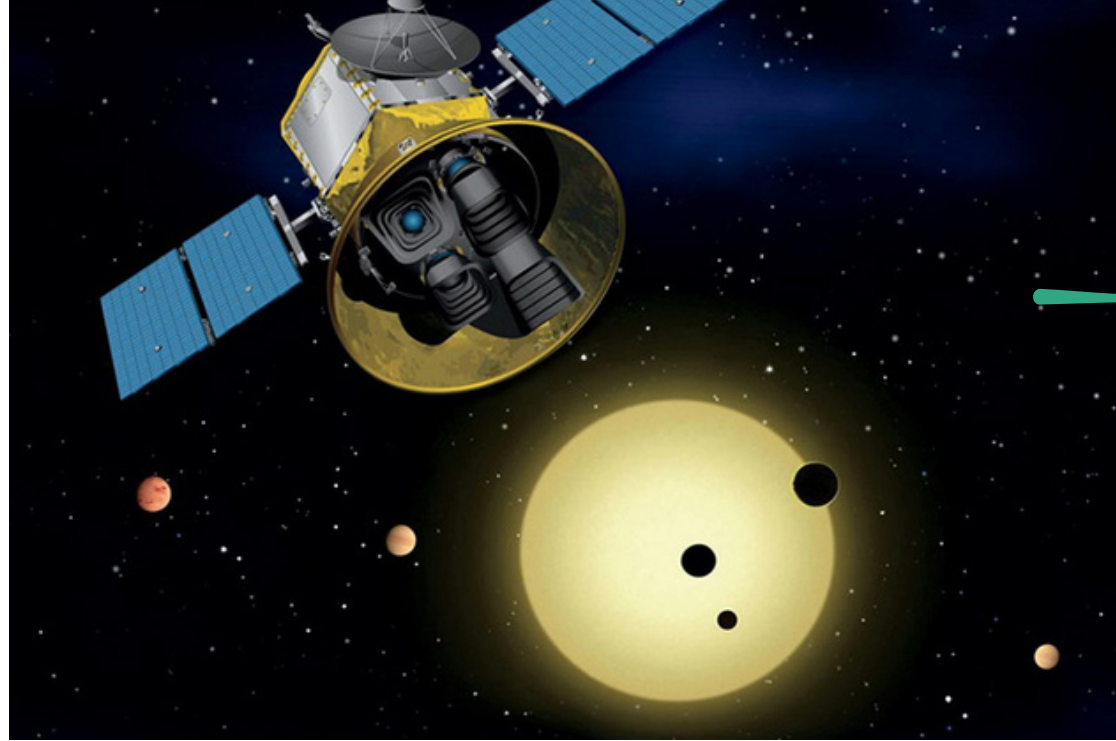
**PUBLIC
DATA!**



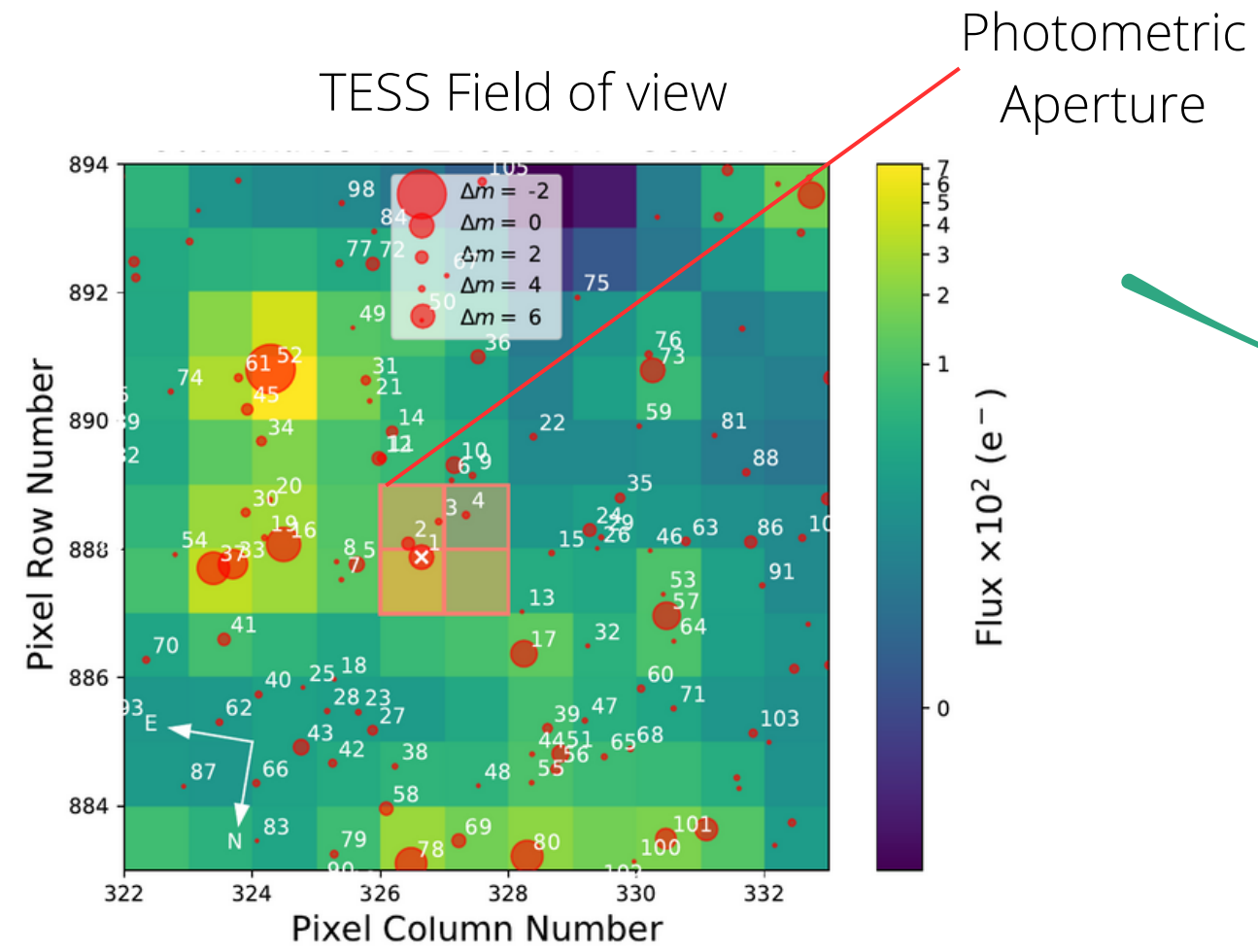
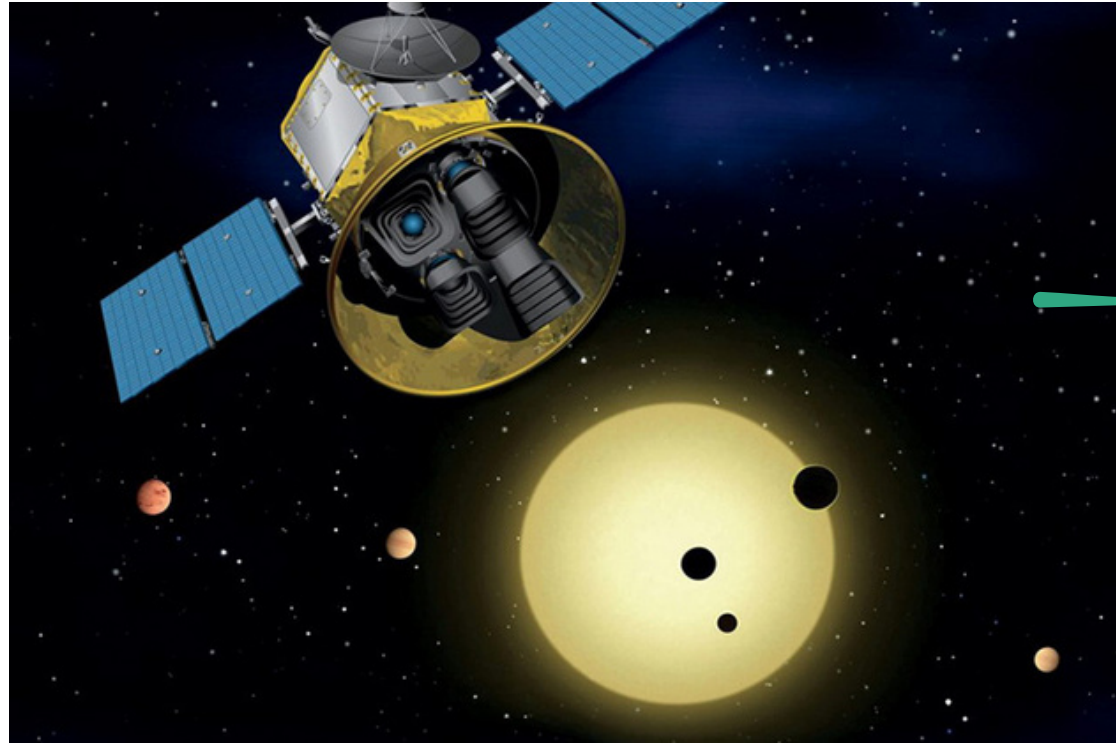
TESS mission



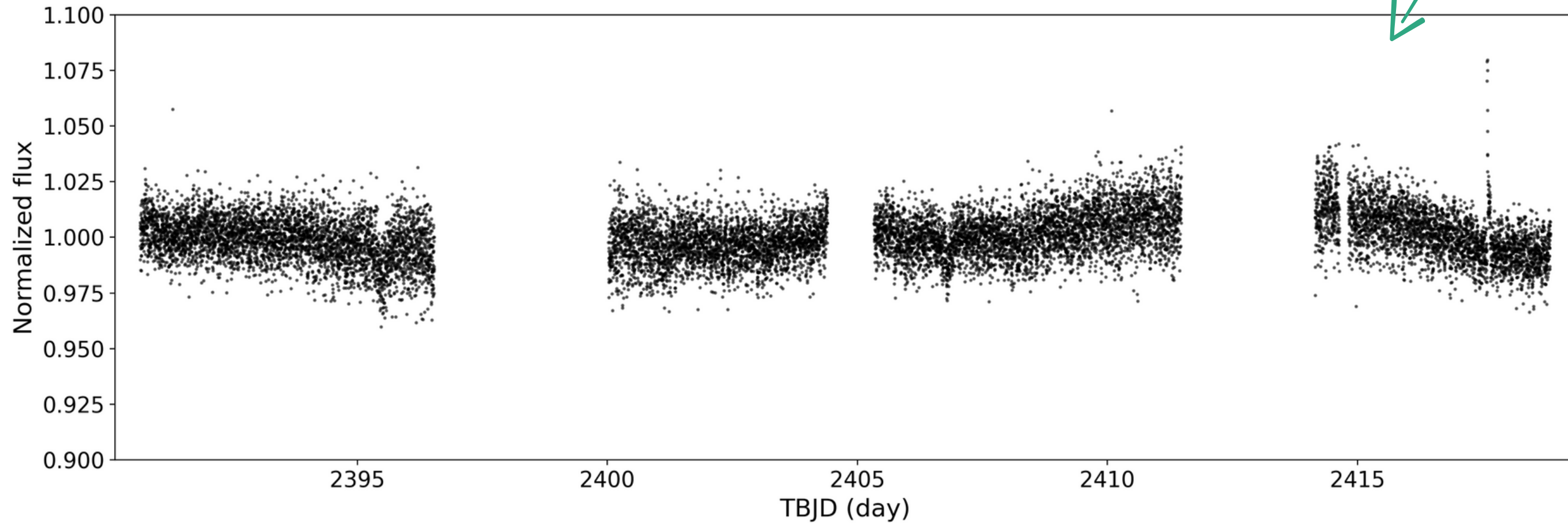
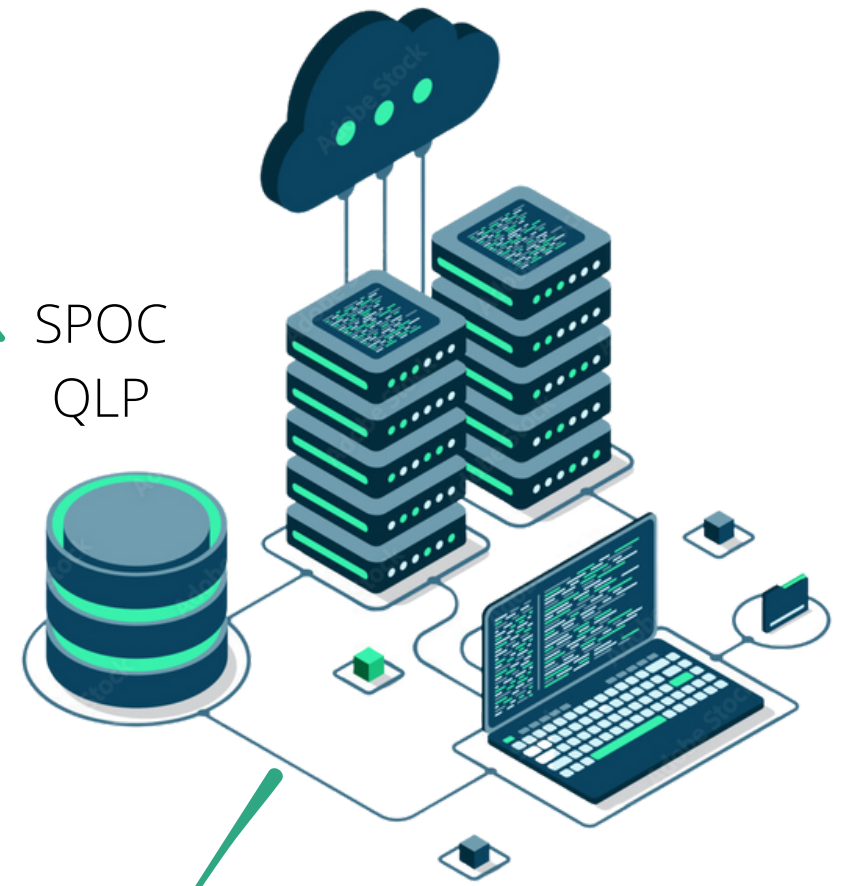
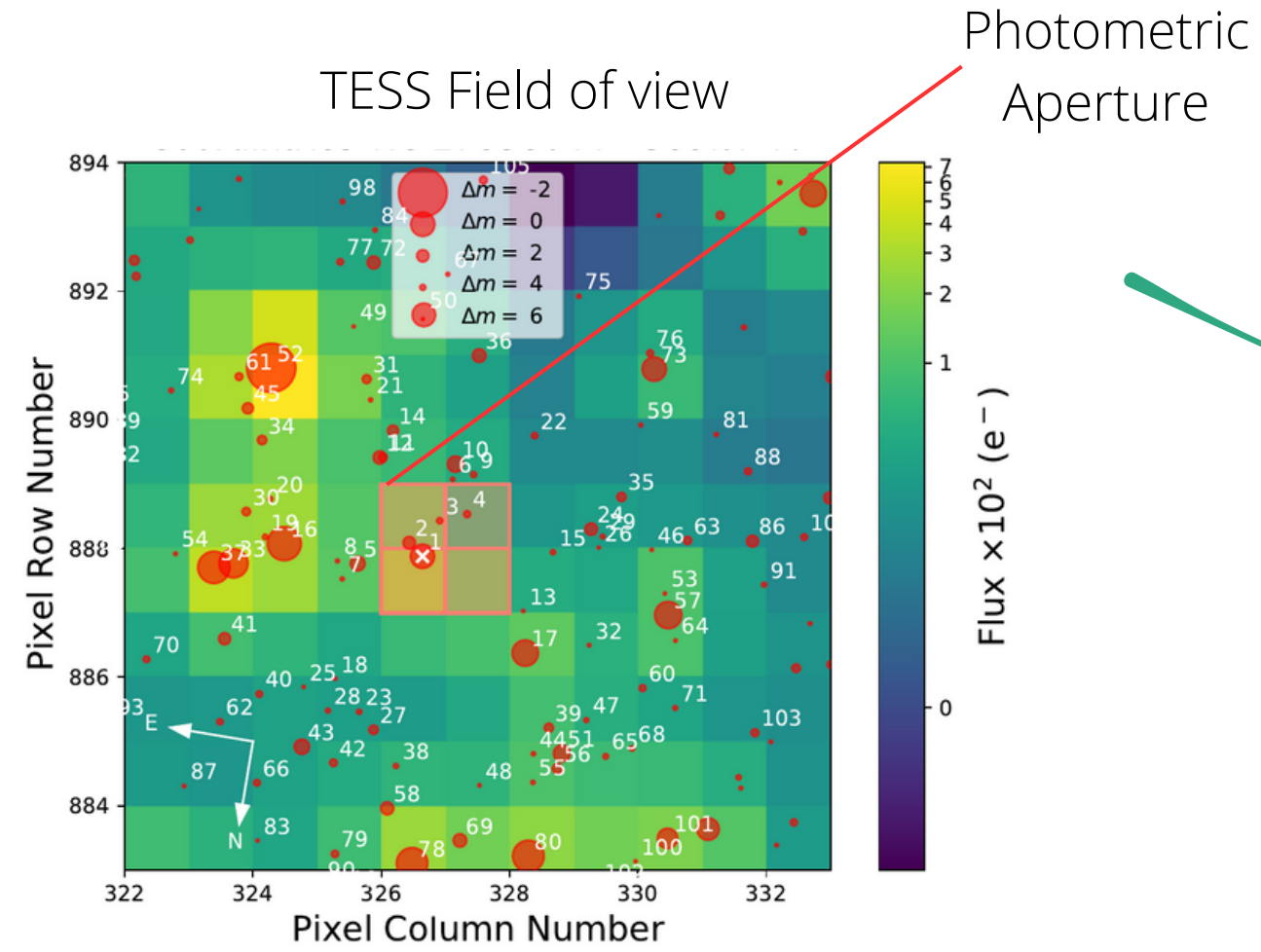
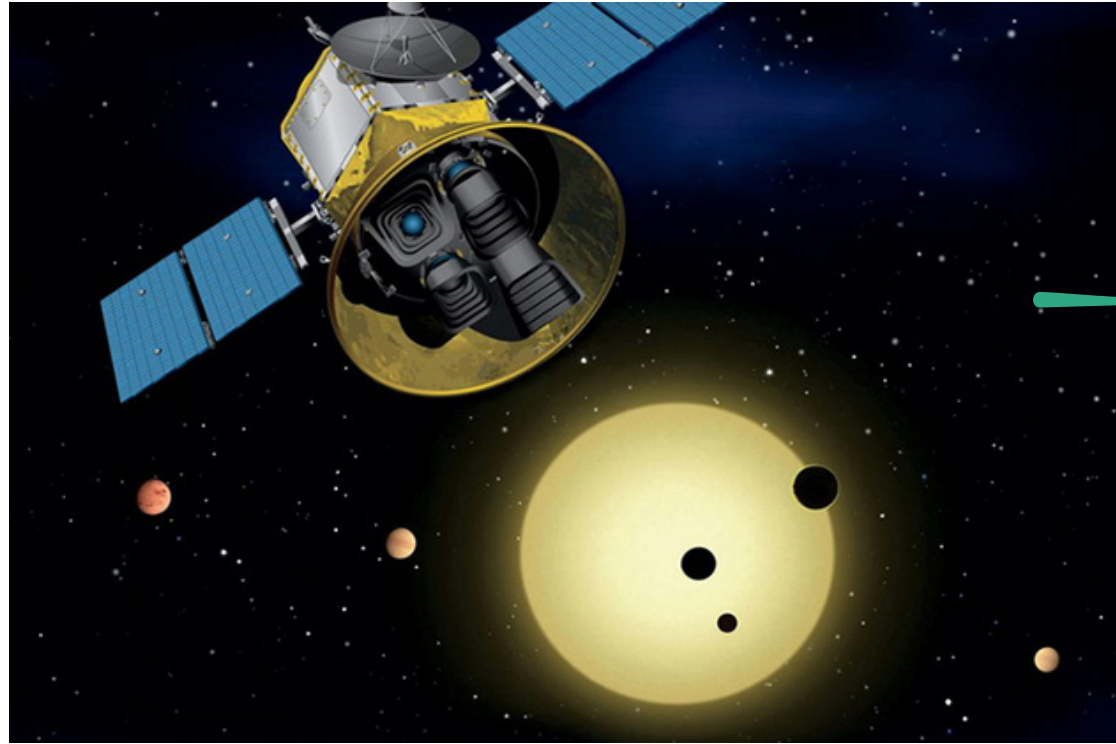
TESS mission



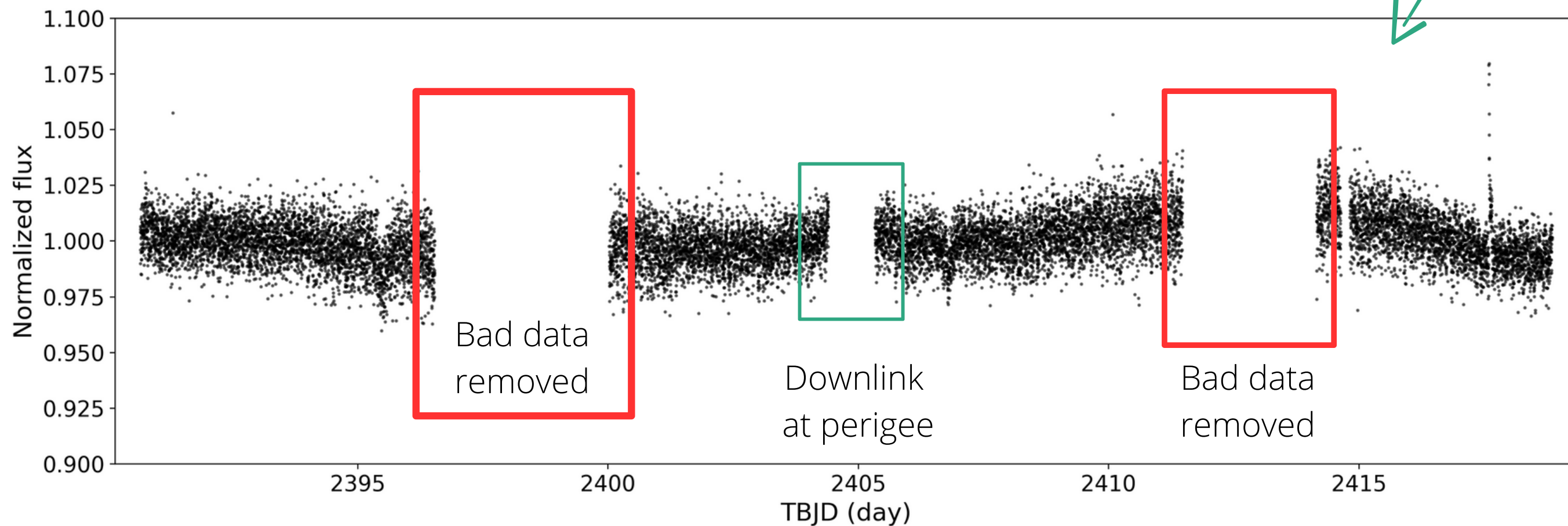
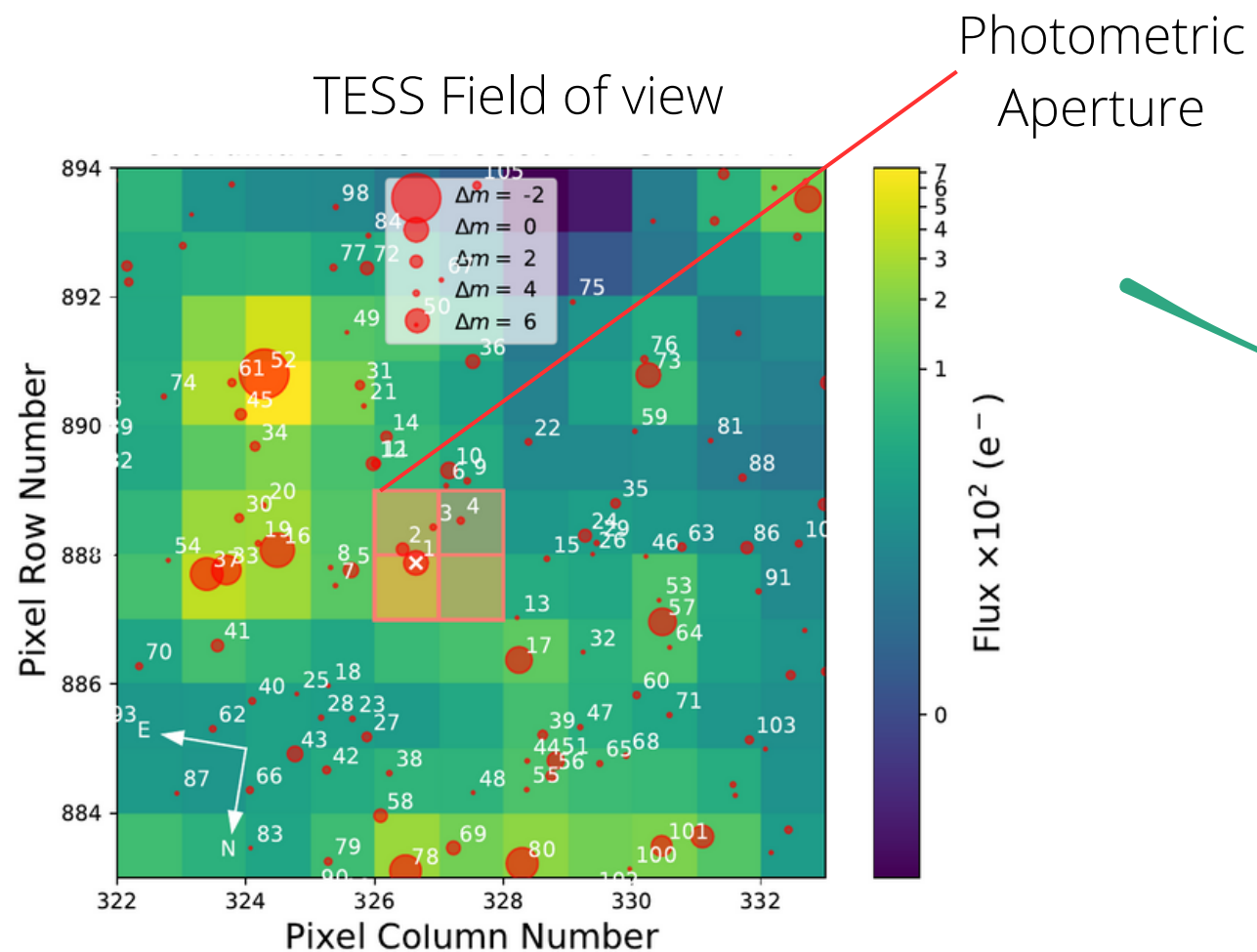
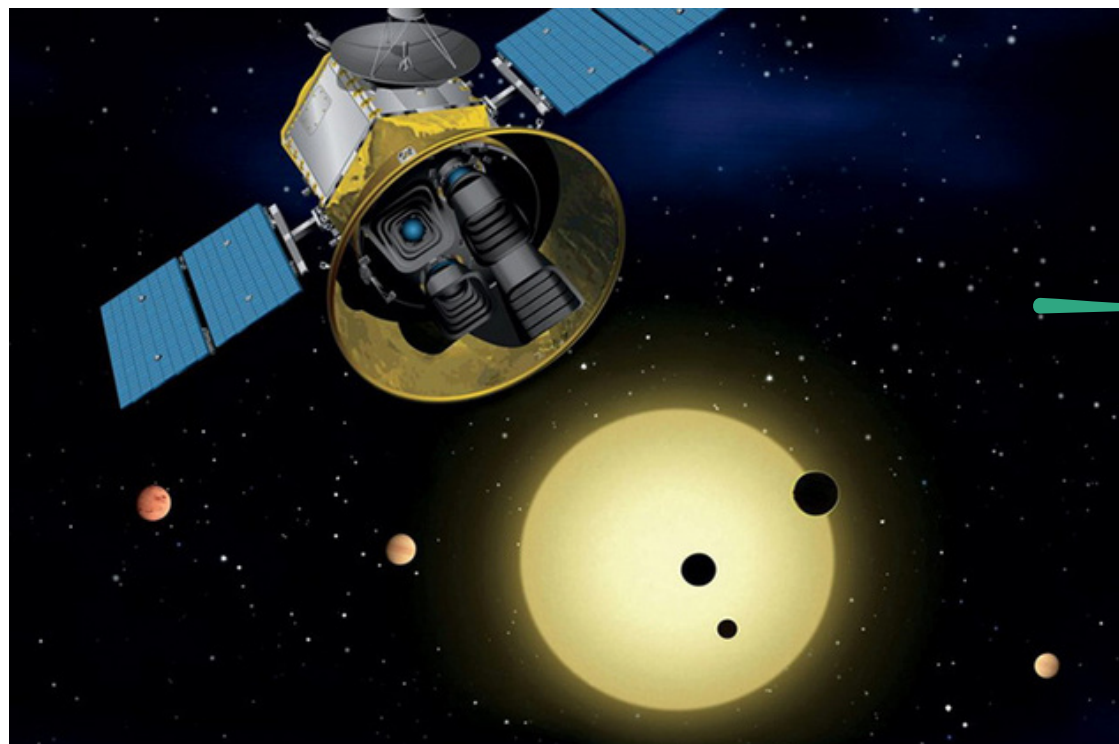
TESS mission



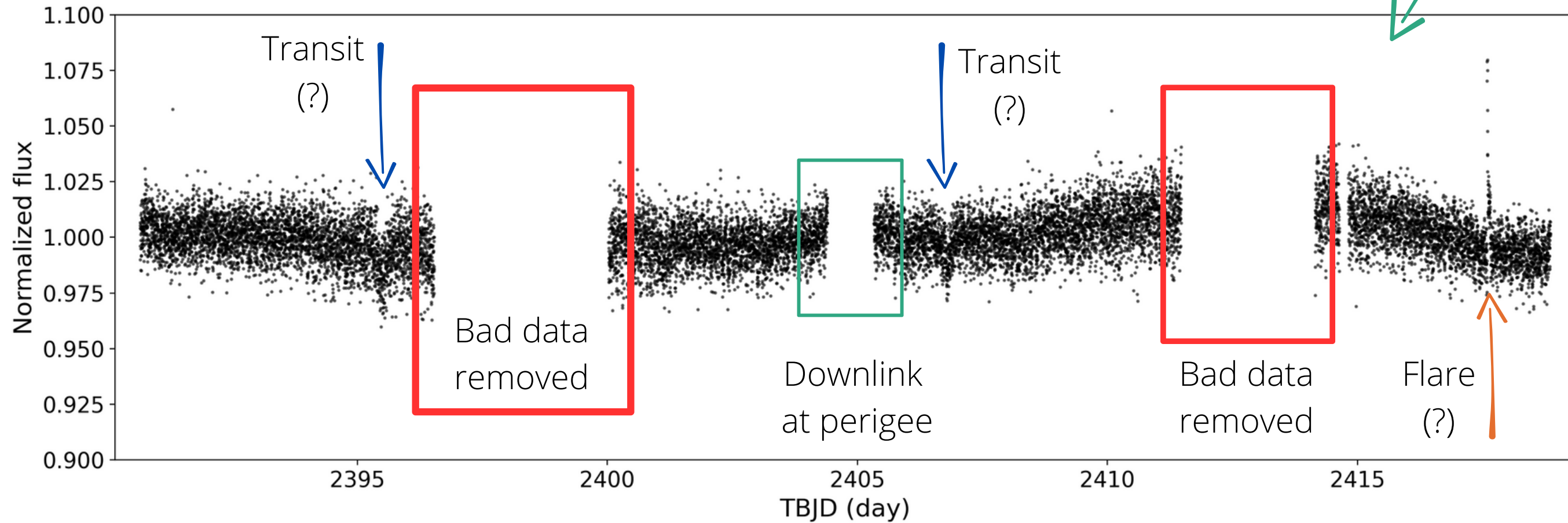
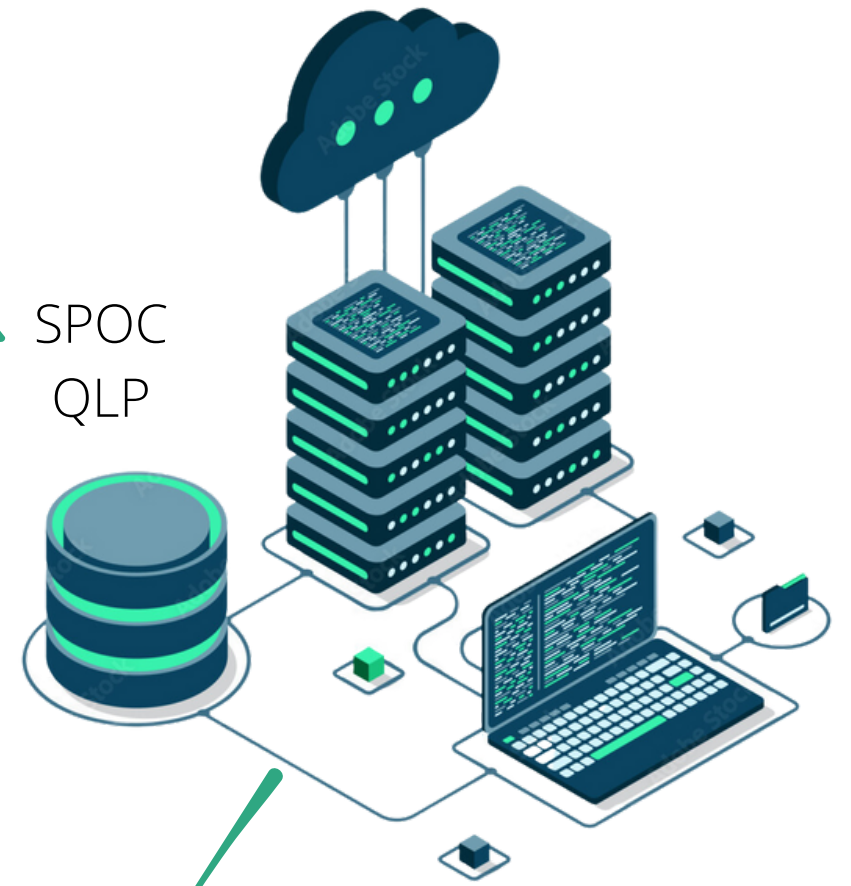
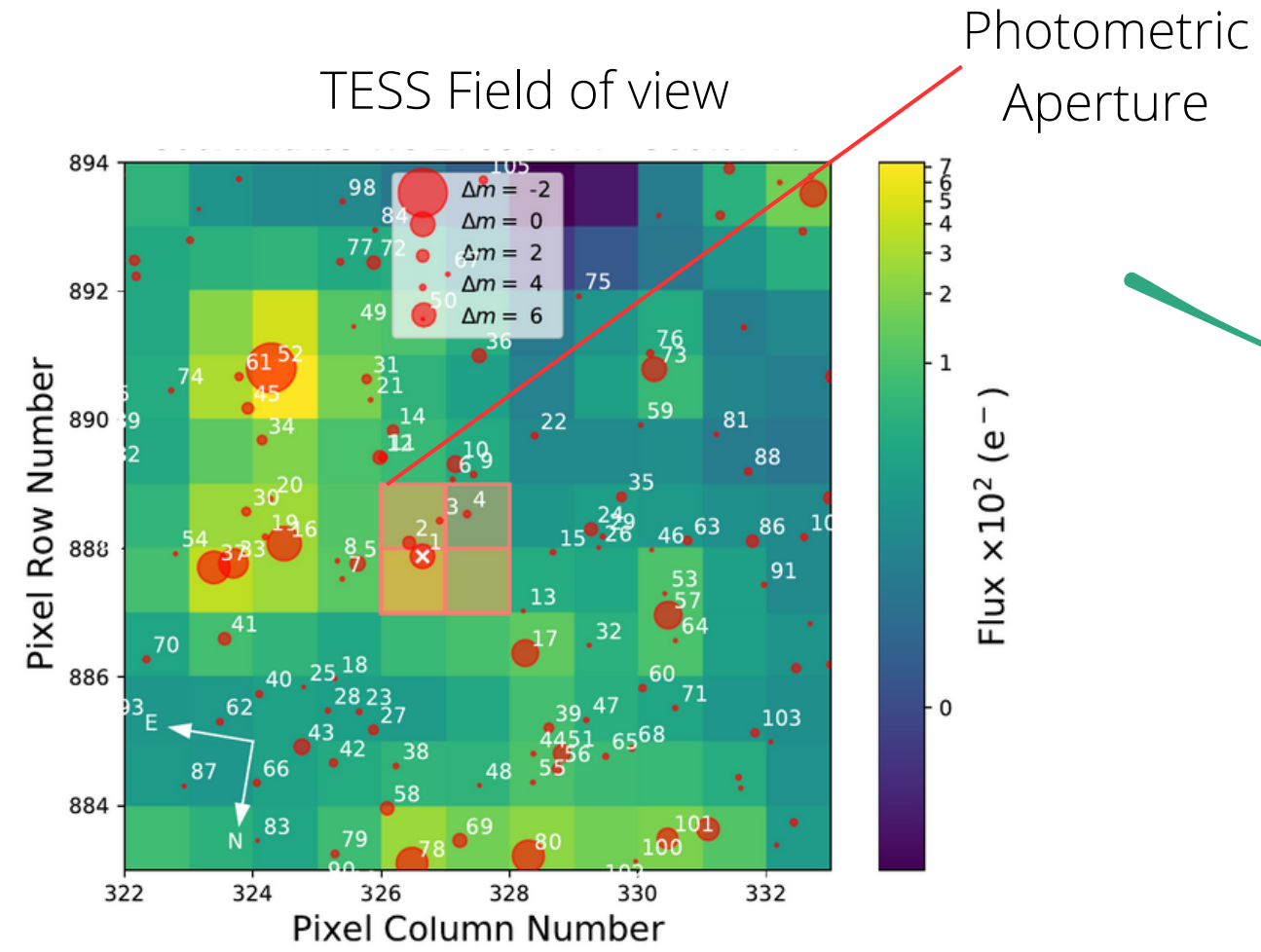
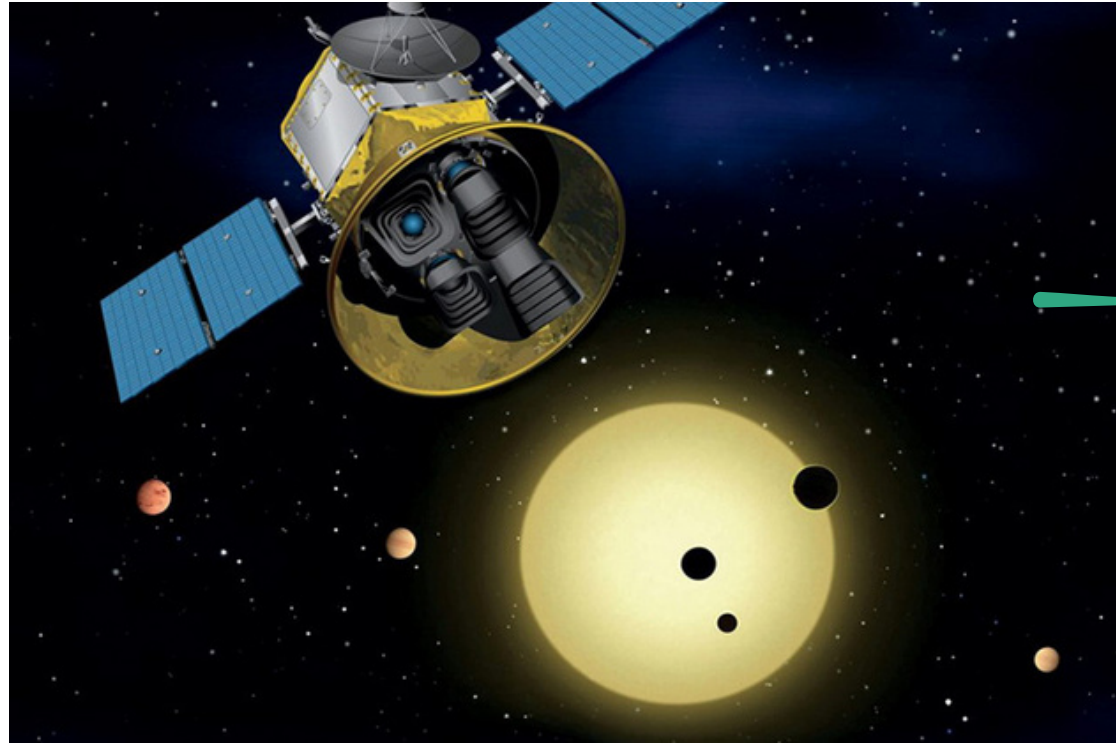
TESS mission



TESS mission



TESS mission



TESS mission



Where are all the TESS data products?

<https://archive.stsci.edu/>

TESS mission

Hundreds of millions of data!
No easy to navigate through it



Where are all the TESS
data products?

<https://archive.stsci.edu/>

TESS mission

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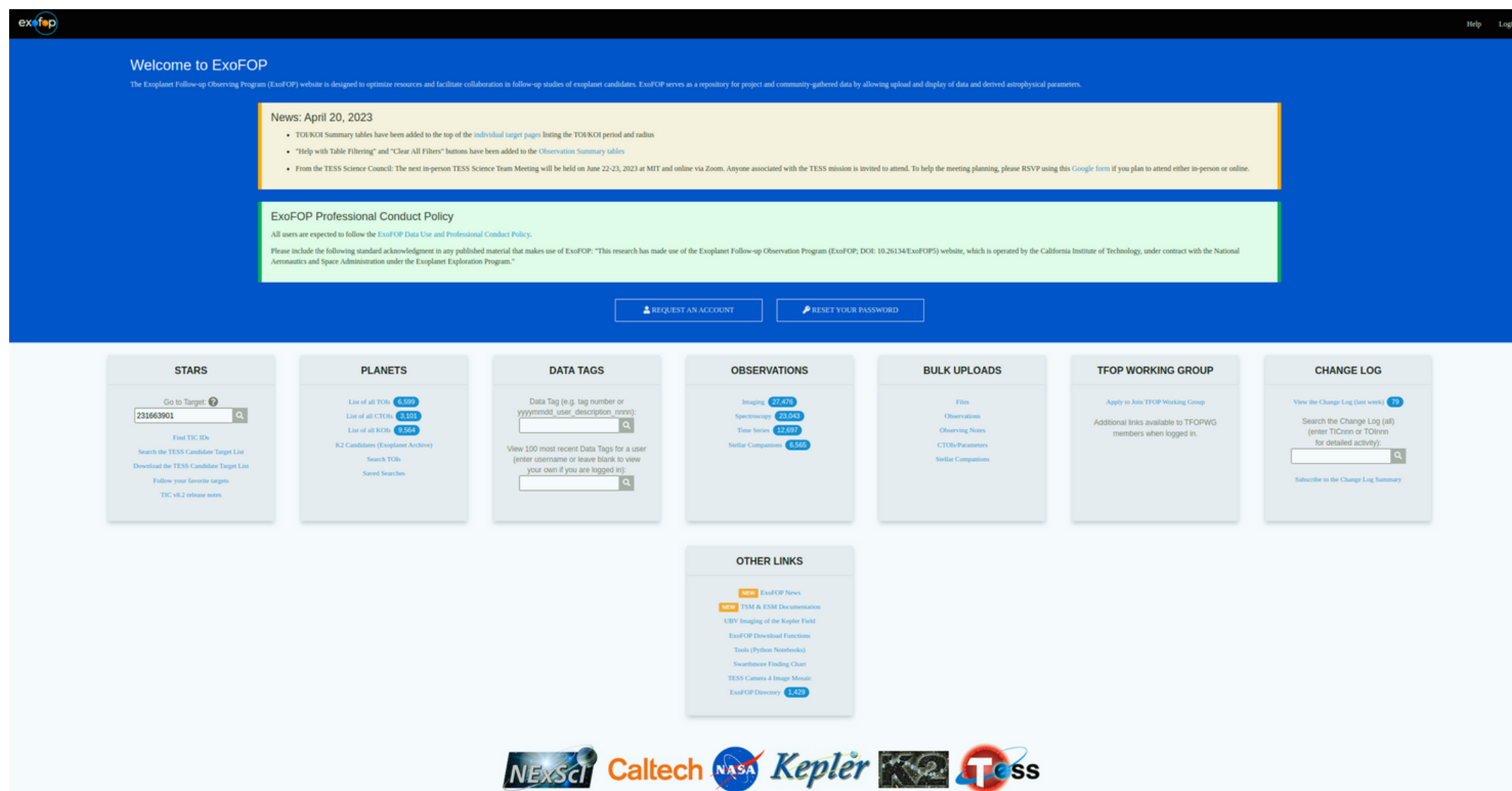
Barbara A. MIKULSKI ARCHIVE FOR SPACE TELESCOPES

Maximizing the scientific accessibility & productivity of astronomical data.

The Mikulski Archive for Space Telescopes is an astronomical data archive focused on the optical, ultraviolet, and near-infrared. MAST hosts data from over a dozen missions like Webb, Hubble, TESS, Kepler, and in the future Roman.

Where are all the TESS data products?

<https://archive.stsci.edu/>



Welcome to ExoFOP

The Exoplanet Follow-up Observing Program (ExoFOP) website is designed to optimize resources and facilitate collaboration in follow-up studies of exoplanet candidates. ExoFOP serves as a repository for project and community-gathered data by allowing upload and display of data and derived astrophysical parameters.

News: April 20, 2023

- TOI/KOI Summary tables have been added to the top of the individual target pages listing the TOI/KOI period and radius
- "Help with Table Filtering" and "Clear All Filters" buttons have been added to the Observation Summary tables
- From the TESS Science Council: The next in-person TESS Science Team Meeting will be held on June 22-23, 2023 at MIT and online via Zoom. Anyone associated with the TESS mission is invited to attend. To help the meeting planning, please RSVP using this Google form if you plan to attend either in-person or online.

ExoFOP Professional Conduct Policy

All users are expected to follow the ExoFOP Data Use and Professional Conduct Policy.

Please include the following standard acknowledgment in any published material that makes use of ExoFOP: "This research has made use of the Exoplanet Follow-up Observing Program (ExoFOP; DOI: 10.26134/ExoFOP) website, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program."

REQUEST AN ACCOUNT | RESET YOUR PASSWORD

STARS: Go to Target: 231663901

PLANETS: List of all TOI: 6,599 | List of all KOI: 3,101 | List of all KOI: 3,564

DATA TAGS: Data Tag (e.g. tag number or yyyyymmdd_user_description_remark)

OBSERVATIONS: Imaging: 27,476 | Spectroscopy: 23,045 | Time Series: 12,697 | Stellar Companions: 6,566

BULK UPLOADS: Files, Observations, Observing Notes, CTIO Parameters, Stellar Companions

TFOP WORKING GROUP: Apply to Join TFOP Working Group

CHANGE LOG: View the Change Log (last week): 78

OTHER LINKS: ExoFOP News, TSM & ESM Documentation, LIBV Imaging of the Kepler Field, ExoFOP Download Functions, Tools (Python Notebooks), Swathmore Finding Chart, TESS Camera 4 Image Mosaic, ExoFOP Directory: 1,429

NExSci | Caltech | NASA | Kepler | TESS

Where are all the TESS alerts?

<https://exofop.ipac.caltech.edu/tess/>

Why SHERLOCK?

Why SHERLOCK?

- Easy access to the TESS data

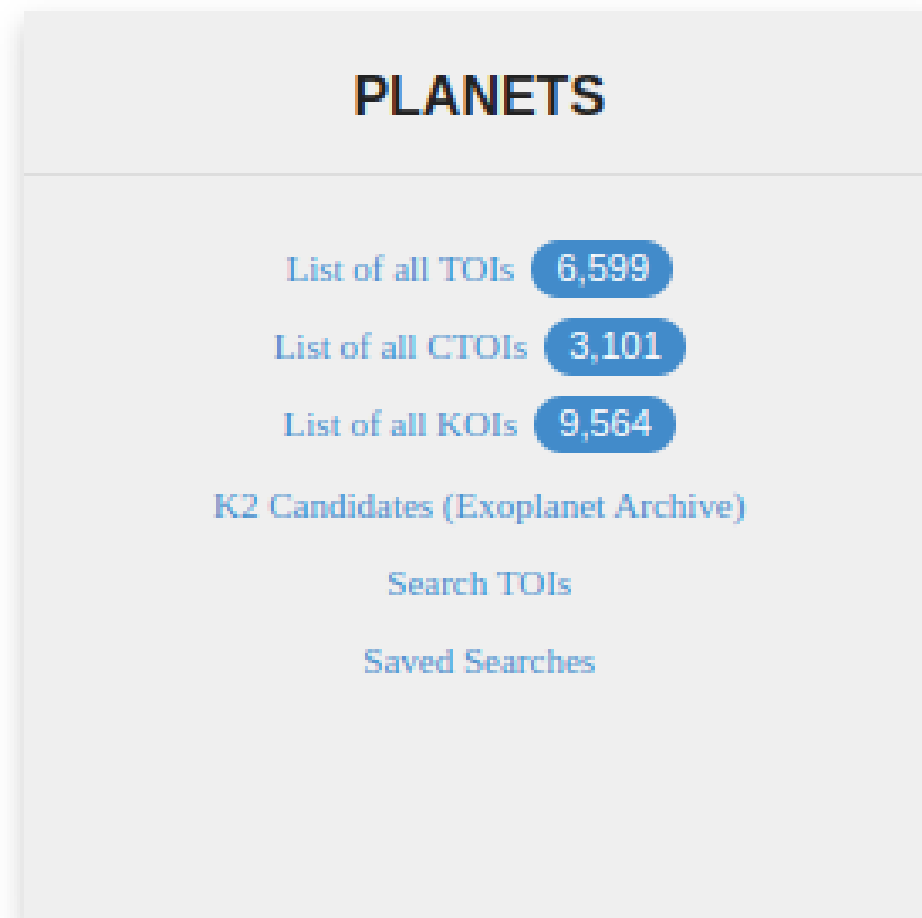


Just using the TIC-ID!



Why SHERLOCK?

- Easy access to the TESS data
- Recover the alerted TOIs or CTOIs



TESS **O**bjects of **I**nterest (TOIs)

Community **T**ESS **O**bjects of **I**nterest (CTOIs)

<https://exofop.ipac.caltech.edu/tess/>

Why SHERLOCK?









- Easy access to the TESS data
- Recover the alerted TOIs or CTOIs
- Search for unnoticed exoplanets

TOI	Period (days)	Radius (R_{\oplus})
736.01	4.99	2.284
736.02	0.948	1.201

THE ASTROPHYSICAL JOURNAL LETTERS

OPEN ACCESS

A Super-Earth and Sub-Neptune Transiting the Late-type M Dwarf LP 791-18

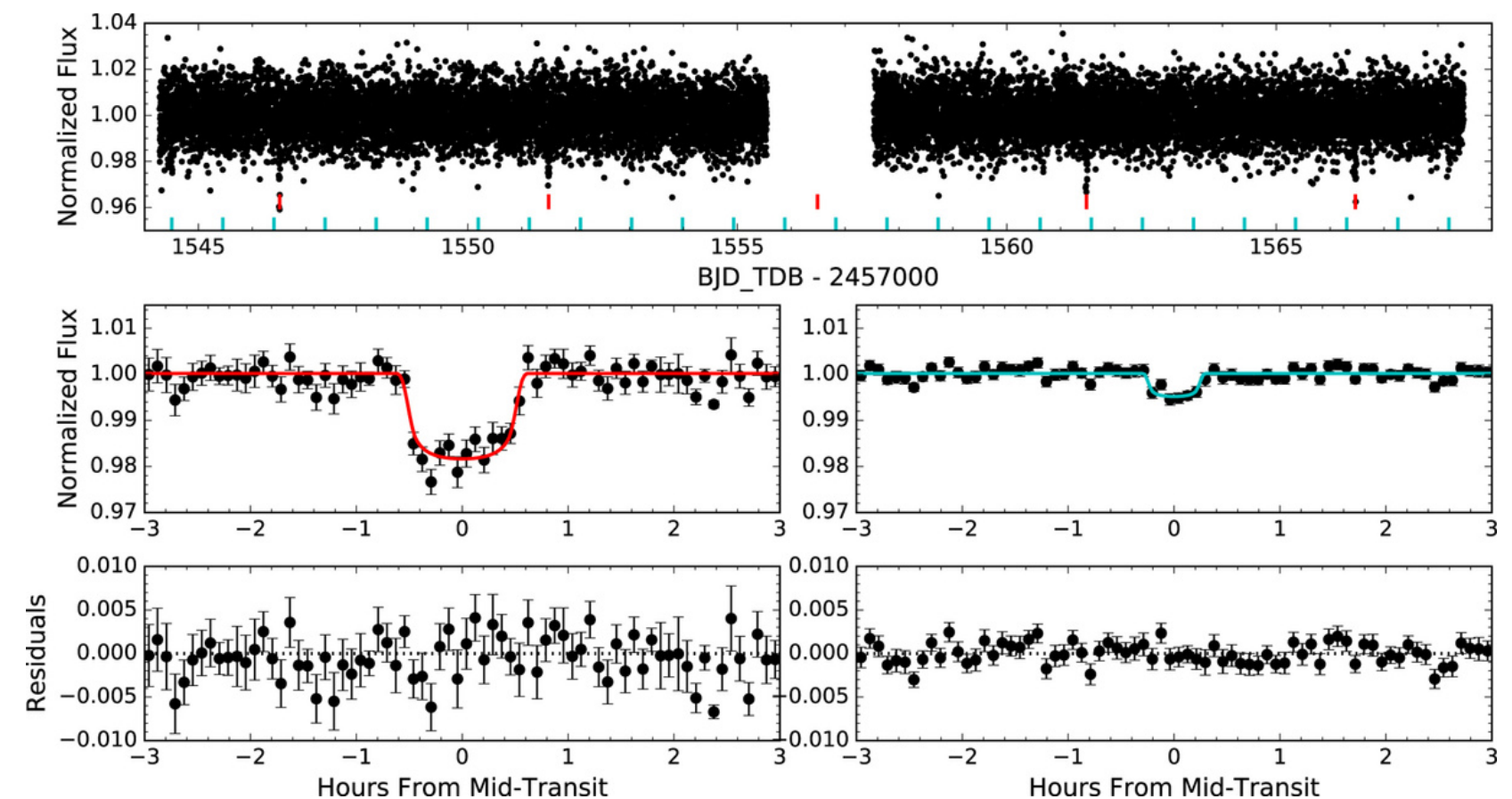
Ian J. M. Crossfield¹, William Waalkes^{33,2} , Elisabeth R. Newton³ , Norio Narita^{4,5,6,7} , Philip Muirhead⁸ , Kristo Ment⁹ , Elisabeth Matthews¹, Adam Kraus¹⁰ , Veselin Kostov¹¹ , Molly R. Kosiarek^{33,12}  + [Show full author list](#)

Published 2019 September 19 • © 2019. The American Astronomical Society.

[The Astrophysical Journal Letters, Volume 883, Number 1](#)

Citation Ian J. M. Crossfield *et al* 2019 *ApJL* **883** L16

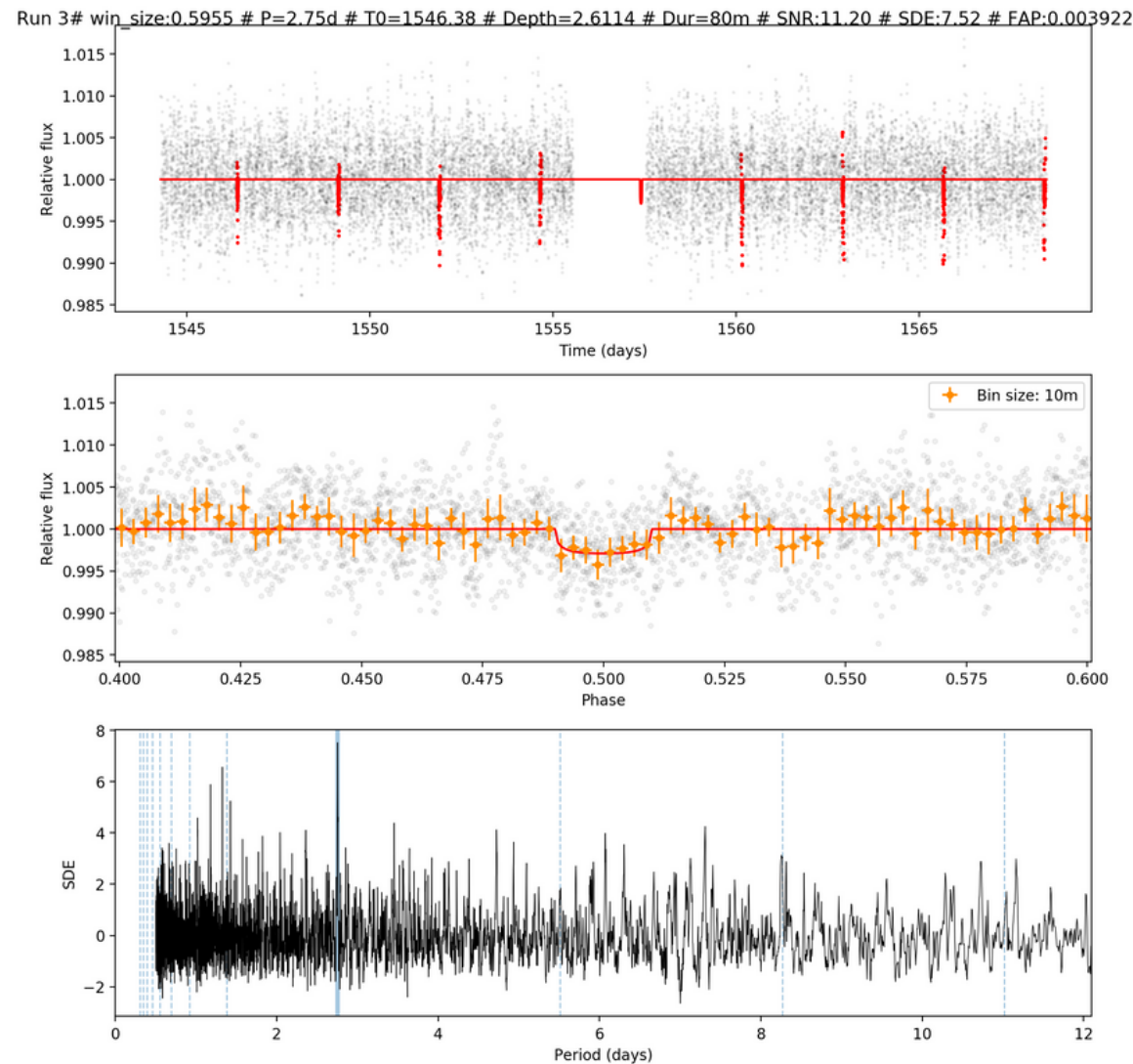
DOI 10.3847/2041-8213/ab3d30



(Crossfield *et al.* 2019)

Why SHERLOCK?

- Easy access to the TESS data
- Recover the alerted TOIs or CTOIs
- Search for unnoticed exoplanets



SHERLOCK detection!

nature

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nature > articles > article

Article | Published: 17 May 2023

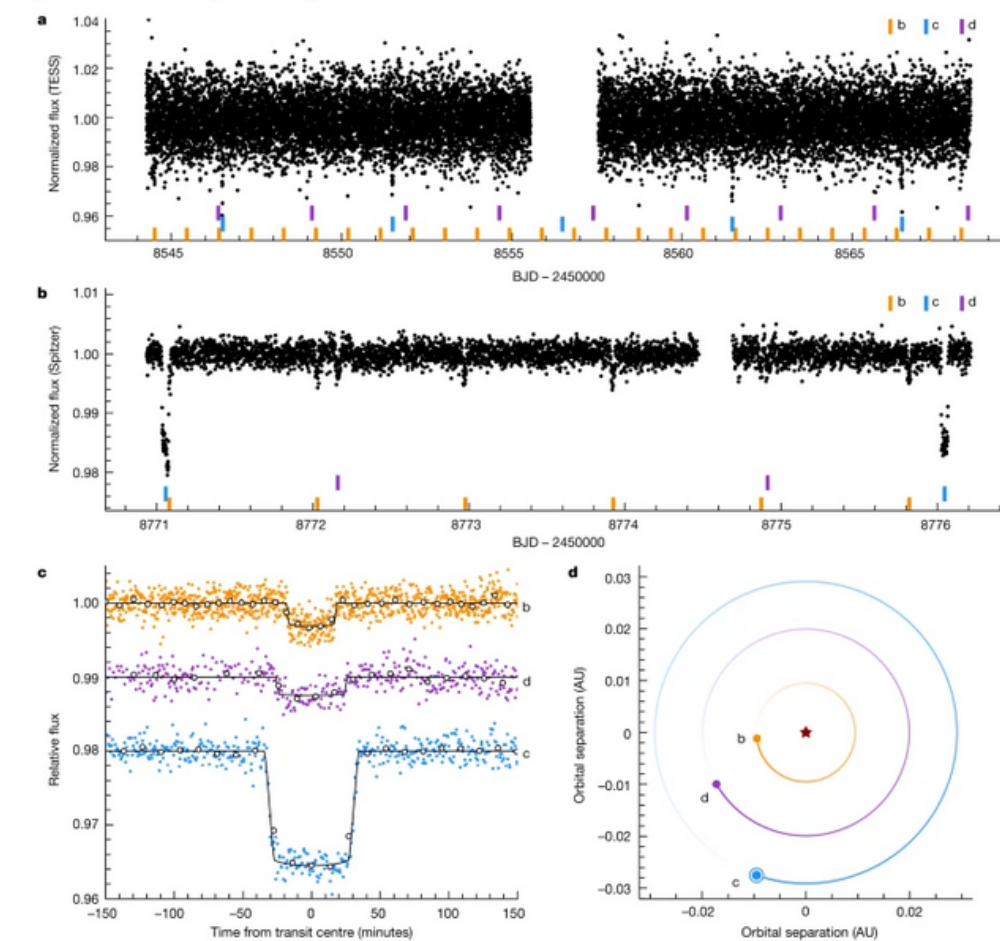
A temperate Earth-sized planet with tidal heating transiting an M6 star

Merrin S. Peterson, Björn Benneke , Karen Collins, Caroline Piaulet, Ian J. M. Crossfield, Mohamad Ali-Dib, Jessie L. Christiansen, Jonathan Gagné, Jackie Faherty, Edwin Kite, Courtney Dressing, David Charbonneau, Felipe Murgas, Marion Cointepas, Jose Manuel Almenara, Xavier Bonfils, Stephen Kane, Michael W. Werner, Varoujan Gorjian, Pierre-Alexis Roy, Avi Shporer, Francisco J. Pozuelos, Quentin Jay Socia, Ryan Cloutier, ... Thomas Barclay  Show authors

Nature 617, 701–705 (2023) | Cite this article

2875 Accesses | 985 Altmetric | Metrics

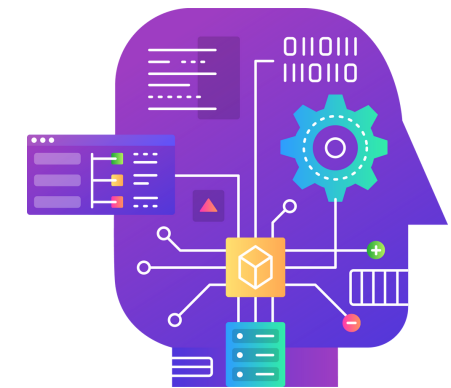
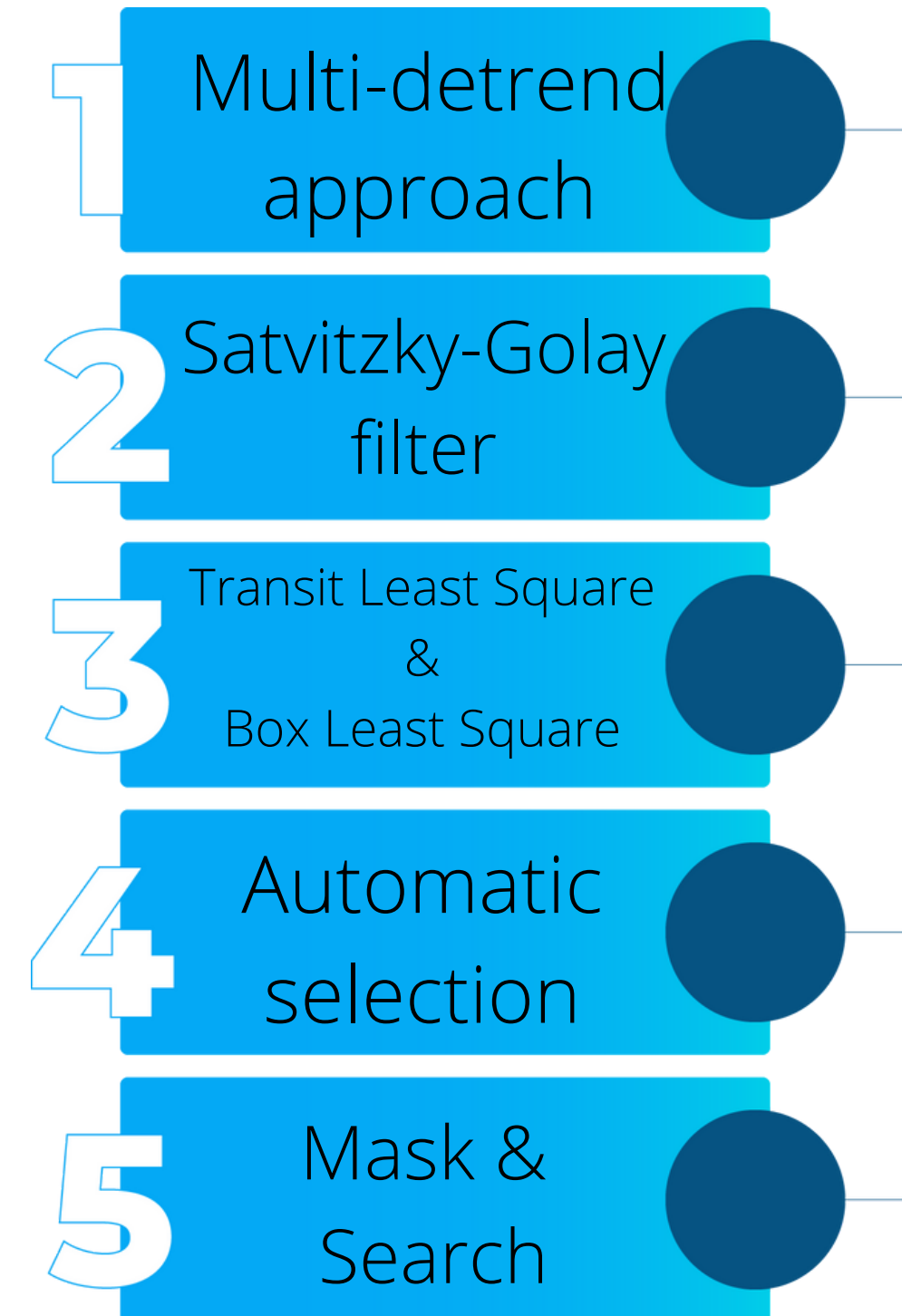
Fig. 1: TESS and Spitzer light curves of LP 791-18.



(Peterson et al. 2023)

Why SHERLOCK?

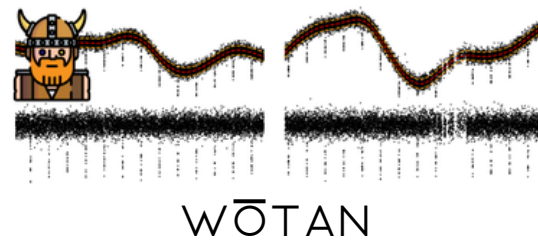
- Easy access to the TESS data
- Recover the alerted TOIs or CTOIs
- Search for unnoticed exoplanets
- Enhanced detection algorithm



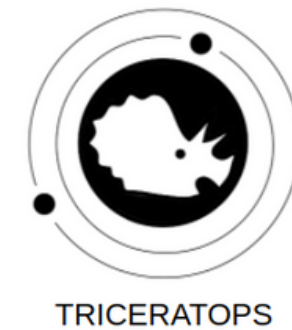
Why SHERLOCK?

- Easy access to the TESS data
- Recover the alerted TOIs or CTOIs
- Search for unnoticed exoplanets
- Enhanced detection algorithm
- End-to-End public pipeline available on GitHub

Lightkurve



Transit Least
Squares



A
ALLESFITTER



From data exploration to trigger an accurate ground-based observation campaign
using **only 6 command lines!**

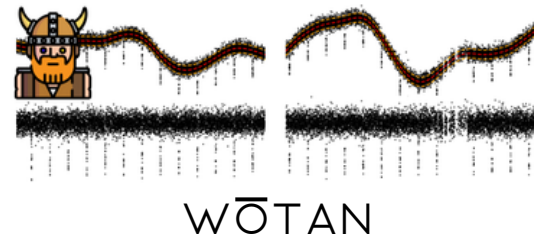
(II) Workflow and scientific cases

- The six SHERLOCK modules
- Examples of scientific cases:
 - SPECULOOS
 - FATE



The six SHERLOCK modules

Lightkurve

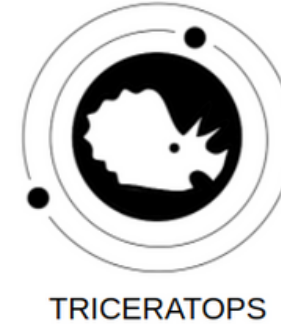


WÖTAN

Transit Least
Squares



WATSON



TRICERATOPS

A
ALLESFITTER



OBSERVER

The six SHERLOCK modules



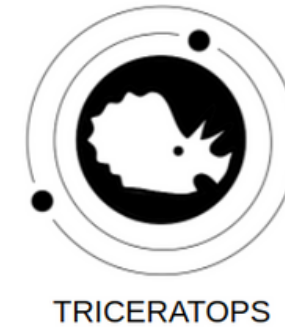
(1)
Prepare the
data



(2)
Search for
candidates



(3)
Vetting



(4)
Statistical
validation



(5)
Fitting



(6)
Observation
plan

The six SHERLOCK modules



6 command lines

- (1) `python3.10 -m sherlockpipe --properties explore.yaml --explore`
- (2) `python3.10 -m sherlockpipe --properties file.yaml`
- (3) `python3.10 -m sherlockpipe.vet --candidate x`
- (4) `python3.10 -m sherlockpipe.validate --candidate x`
- (5) `python3.10 -m sherlockpipe.fit --candidate x`
- (6) `python3.10 -m sherlockpipe.plan --observatories observatories.csv`

The six SHERLOCK modules



(1)

Prepare the
data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```



The six SHERLOCK modules



(1)

Prepare the data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```



```
Abrir  explore.yaml  Guardar  -  x
~/Escritorio/EXOPLANETAS...

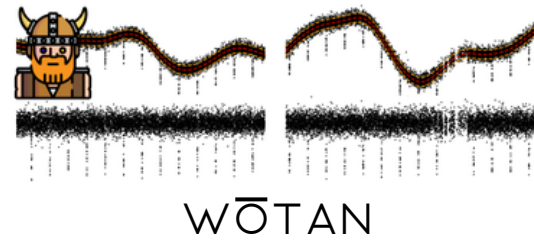
1 TARGETS:
2 TIC xxxxxxxx:
3   MODE: GLOBAL
4   AUTO_DETREND_ENABLED: True
5   INITIAL_HIGH_RMS_MASK: True
6   INITIAL_SMOOTH_ENABLED: True
7   INITIAL_HIGH_RMS_THRESHOLD: 2
8   EXPTIME: 120
9   DETREND_L_MIN: 0.2
10  DETREND_L_MAX: 1.2
11  DETRENDS_NUMBER: 10
12  DETREND_CORES: 10
13  CPU_CORES: 45
14  MAX_RUNS: 2
15  SNR_MIN: 5
16  SDE_MIN: 5
17  PERIOD_MIN: 1
18  PERIOD_MAX: 15
19  UPDATE_OIS: True
20
21
22
```



TICxxxxxxx_explore

The six SHERLOCK modules

Lightkurve



(1)

Prepare the data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```



```
Abrir  explore.yaml  Guardar  -  x
~/Escritorio/EXOPLANETAS...

1 TARGETS:
2 TIC xxxxxxxx:
3   MODE: GLOBAL
4   AUTO_DETREND_ENABLED: True
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6   INITIAL_SMOOTH_ENABLED: True
7   INITIAL_HIGH_RMS_THRESHOLD: 2
8   EXPTIME: 120
9   DETREND_L_MIN: 0.2
10  DETREND_L_MAX: 1.2
11  DETRENDS_NUMBER: 10
12  DETREND_CORES: 10
13  CPU_CORES: 45
14  MAX_RUNS: 2
15  SNR_MIN: 5
16  SDE_MIN: 5
17  PERIOD_MIN: 1
18  PERIOD_MAX: 15
19  UPDATE_OIS: True
20
21
22
```



TICxxxxxxx_explore

- How does the photometry look like?
- How many sectors are available?
- Which cadences are available?
- Is it a fast rotator?
- Are there some noisy regions?
- Which is the field-of-view?

The six SHERLOCK modules



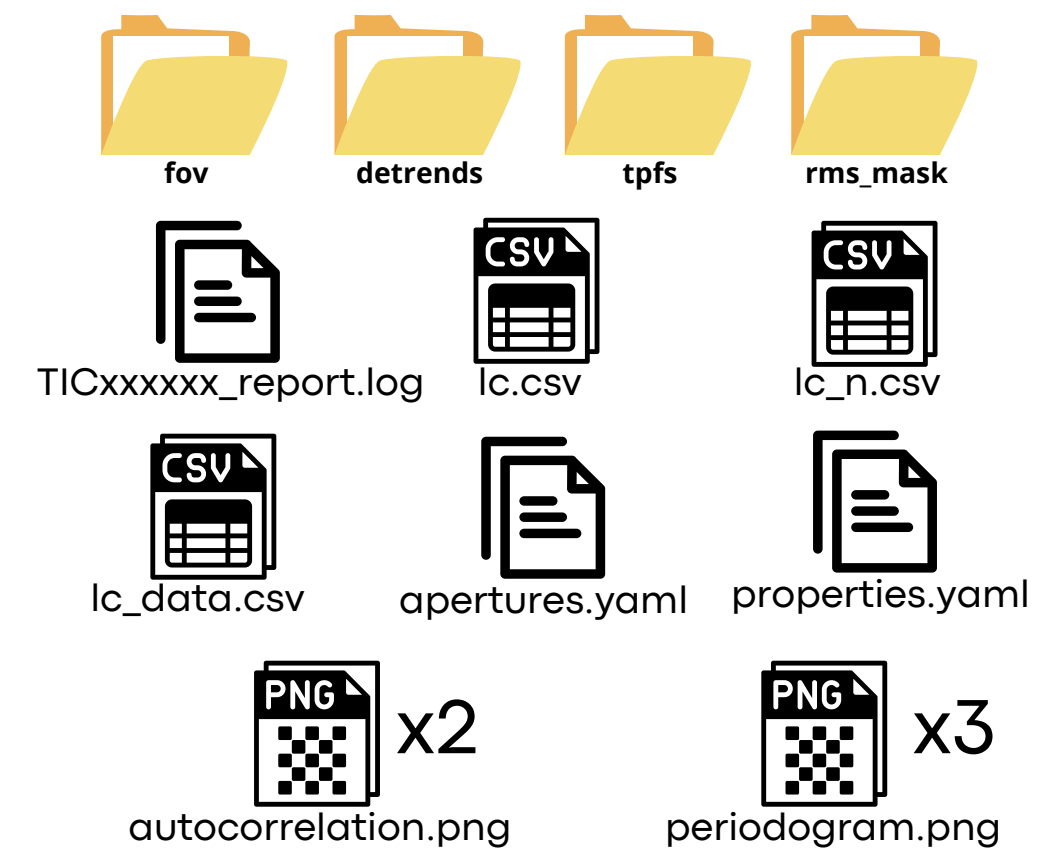
(1)

Prepare the data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

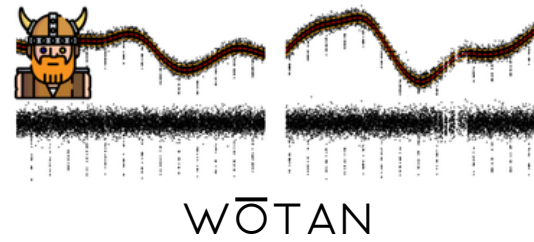
```
Abrir  explore.yaml  Guardar  -  x
~/Escritorio/EXOPLANETAS...

1 TARGETS:
2 TIC xxxxxxx:
3  MODE: GLOBAL
4  AUTO_DETREND_ENABLED: True
5  INITIAL_HIGH_RMS_MASK: True
6  INITIAL_SMOOTH_ENABLED: True
7  INITIAL_HIGH_RMS_THRESHOLD: 2
8  EXPTIME: 120
9  DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```



The six SHERLOCK modules

Lightkurve



(1)
Prepare the data



```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```



```
Abrir  explore.yaml  Guardar  -  x
~/Escritorio/EXOPLANETAS...

1 TARGETS:
2 TIC xxxxxxx:
3   MODE: GLOBAL
4   AUTO_DETREND_ENABLED: True
5   INITIAL_HIGH_RMS_MASK: True
6   INITIAL_SMOOTH_ENABLED: True
7   INITIAL_HIGH_RMS_THRESHOLD: 2
8   EXPTIME: 120
9   DETREND_L_MIN: 0.2
10  DETREND_L_MAX: 1.2
11  DETRENDS_NUMBER: 10
12  DETREND_CORES: 10
13  CPU_CORES: 45
14  MAX_RUNS: 2
15  SNR_MIN: 5
16  SDE_MIN: 5
17  PERIOD_MIN: 1
18  PERIOD_MAX: 15
19  UPDATE_OIS: True
20
21
22
```

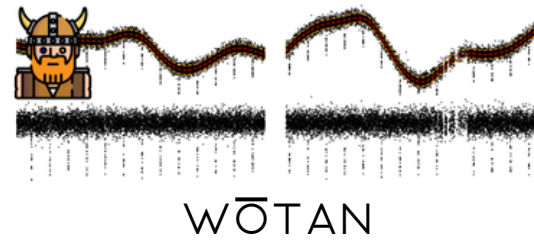
- **MODE: GLOBAL / SECTOR / BOTH**
- **EXPTIME: 20 / 120 / 600 / 1800**
- **PERIOD_MIN: 0.3**
- **PERIOD_MAX: 13**

- How does the photometry look like?
- How many sectors are available?
- Which cadences are available?

```
Retrieving star catalog info...
Downloading lightcurve files...
There is data for Mission: TESS Sector 03, Year 2018, Author: SPOC, ExpTime: 120
There is data for Mission: TESS Sector 03, Year 2018, Author: TESS-SPOC, ExpTime: 1800
There is data for Mission: TESS Sector 04, Year 2018, Author: SPOC, ExpTime: 120
There is data for Mission: TESS Sector 04, Year 2018, Author: TESS-SPOC, ExpTime: 1800
There is data for Mission: TESS Sector 05, Year 2018, Author: SPOC, ExpTime: 120
There is data for Mission: TESS Sector 05, Year 2018, Author: TESS-SPOC, ExpTime: 1800
There is data for Mission: TESS Sector 30, Year 2020, Author: SPOC, ExpTime: 20
There is data for Mission: TESS Sector 30, Year 2020, Author: SPOC, ExpTime: 120
There is data for Mission: TESS Sector 30, Year 2020, Author: TESS-SPOC, ExpTime: 600
There is data for Mission: TESS Sector 32, Year 2020, Author: SPOC, ExpTime: 20
There is data for Mission: TESS Sector 32, Year 2020, Author: SPOC, ExpTime: 120
There is data for Mission: TESS Sector 32, Year 2020, Author: TESS-SPOC, ExpTime: 600
```

The six SHERLOCK modules

Lightkurve



(1)

Prepare the data

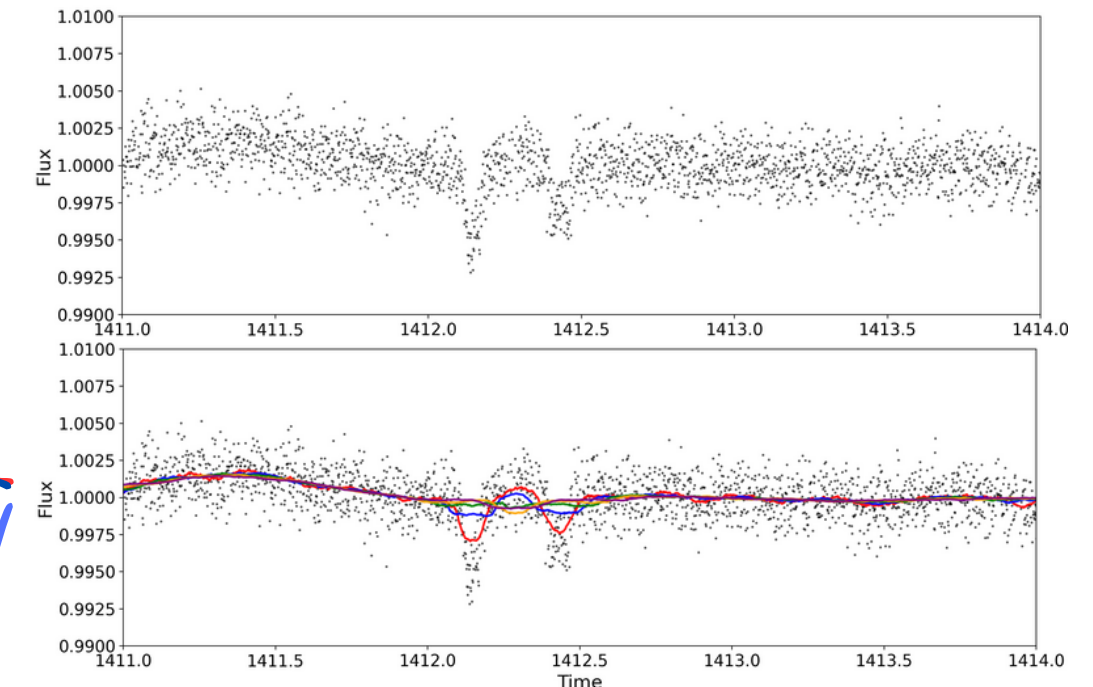
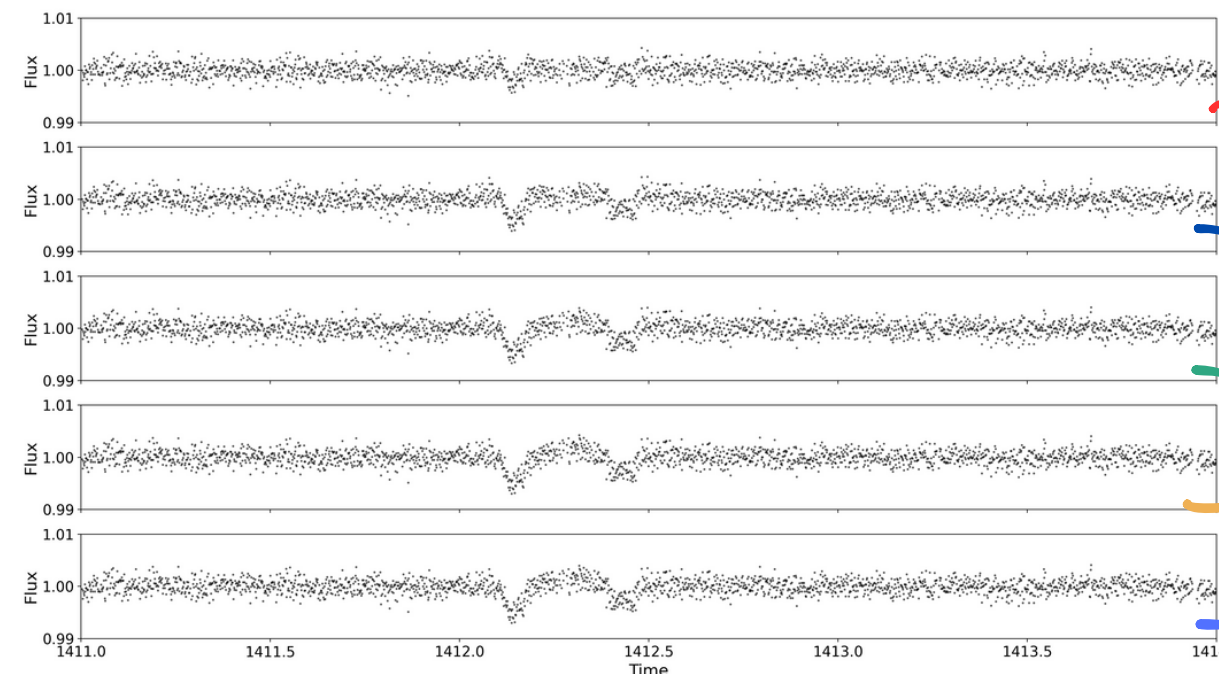
```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```



```
1 TARGETS:
2 TIC xxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```

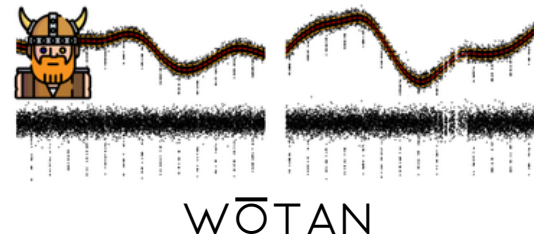
- **DETREND_L_MIN: >0.1**
- **DETREND_L_MAX: <1.3**
- **DETRENDS_NUMBER: 5-10**

• How does the photometry look like?



The six SHERLOCK modules

Lightkurve



Transit Least Squares



ALLESFITTER



(1)

Prepare the data

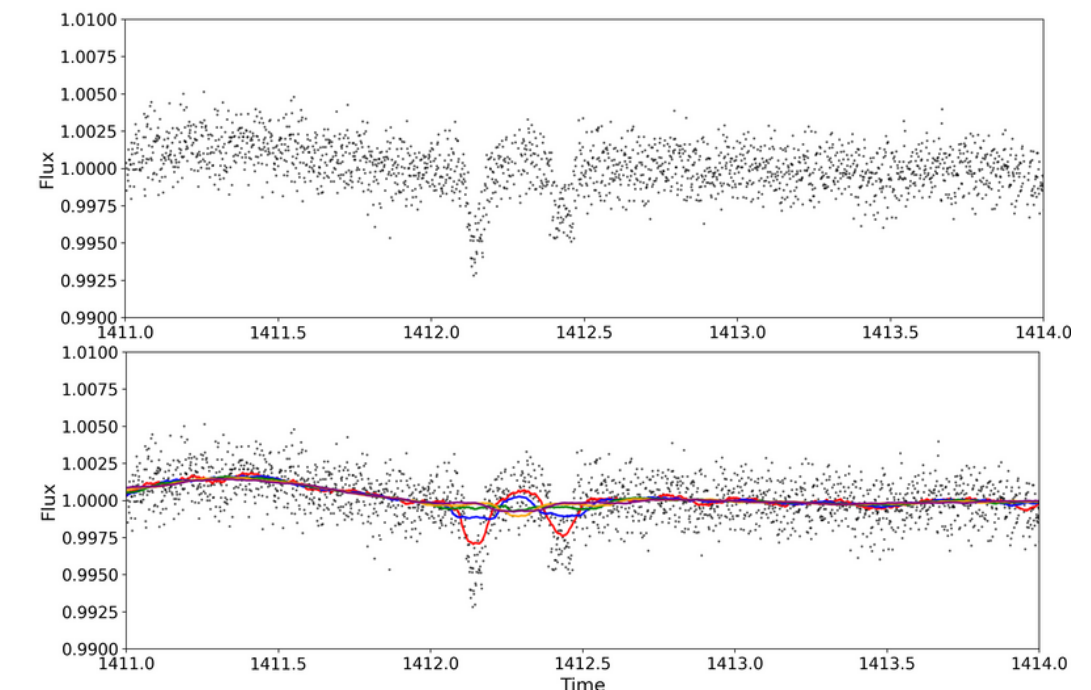
```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```



• How does the photometry look like?

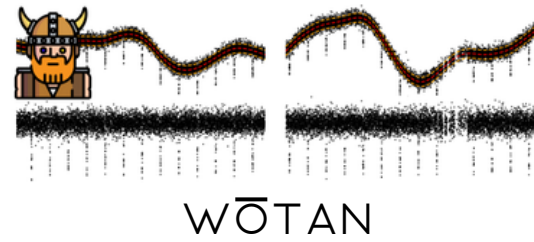
```
1 TARGETS:
2 TIC xxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```

- **DETREND_L_MIN: >0.1**
- **DETREND_L_MAX: <1.3**
- **DETRENDS_NUMBER: 5-10**



The six SHERLOCK modules

Lightkurve




(1)

Prepare the data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

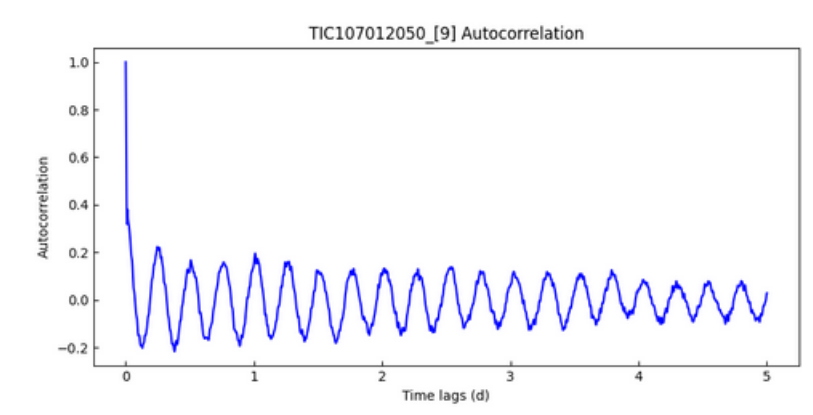
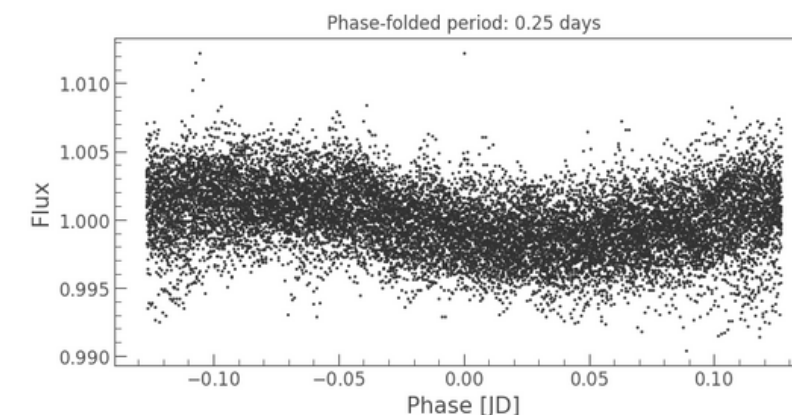
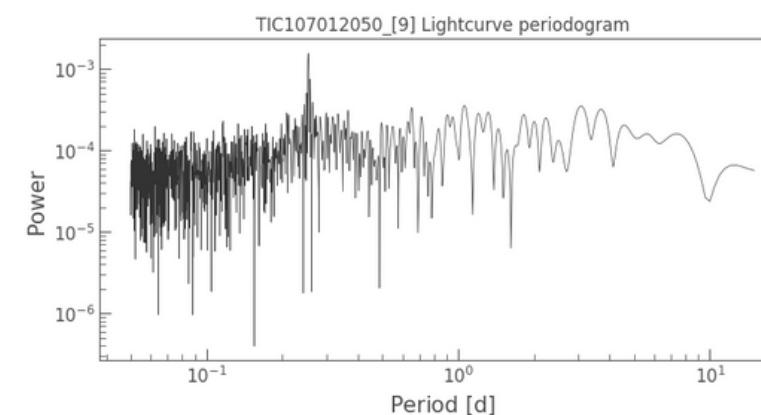
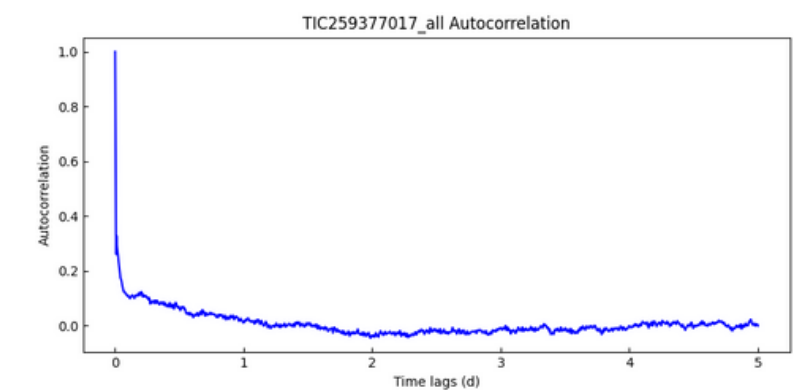
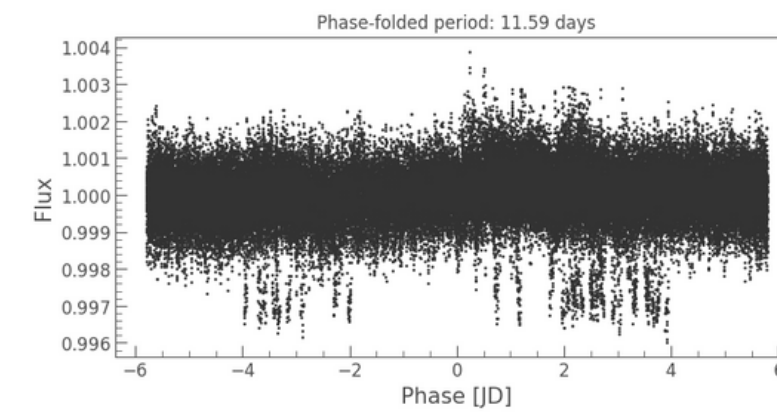
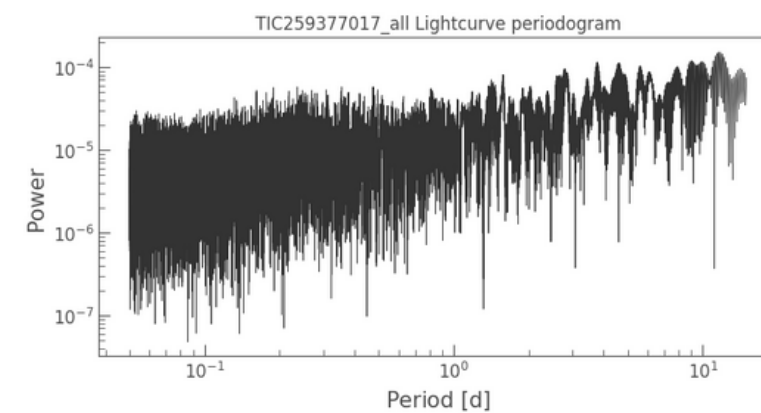
 x2
autocorrelation.png

 x3
periodogram.png

• Is it a fast rotator?

• **AUTO_DETREND_ENABLE: TRUE / FALSE**

```
Abrir  explore.yaml  Guardar  ~/Escritorio/EXOPLANETAS...  
1 TARGETS:  
2 TIC xxxxxxx:  
3 MODE: GLOBAL  
4 AUTO_DETREND_ENABLED: True  
5 INITIAL_HIGH_RMS_MASK: True  
6 INITIAL_SMOOTH_ENABLED: True  
7 INITIAL_HIGH_RMS_THRESHOLD: 2  
8 EXPTIME: 120  
9 DETREND_L_MIN: 0.2  
10 DETREND_L_MAX: 1.2  
11 DETRENDS_NUMBER: 10  
12 DETREND_CORES: 10  
13 CPU_CORES: 45  
14 MAX_RUNS: 2  
15 SNR_MIN: 5  
16 SDE_MIN: 5  
17 PERIOD_MIN: 1  
18 PERIOD_MAX: 15  
19 UPDATE_OIS: True  
20  
21  
22
```



The six SHERLOCK modules



(1)
Prepare the data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

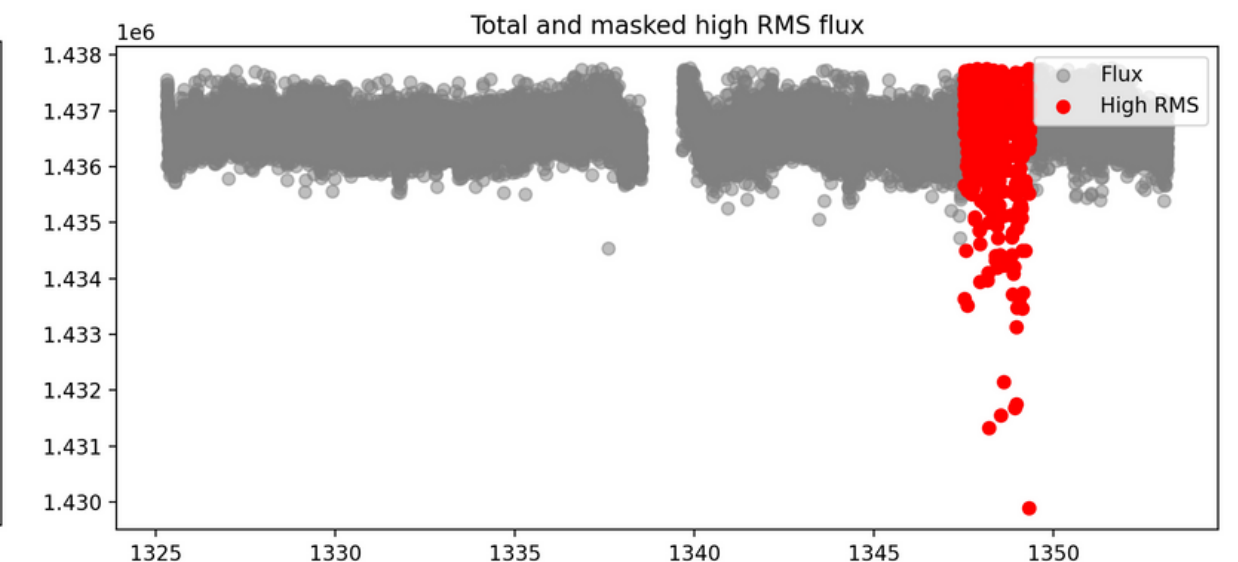
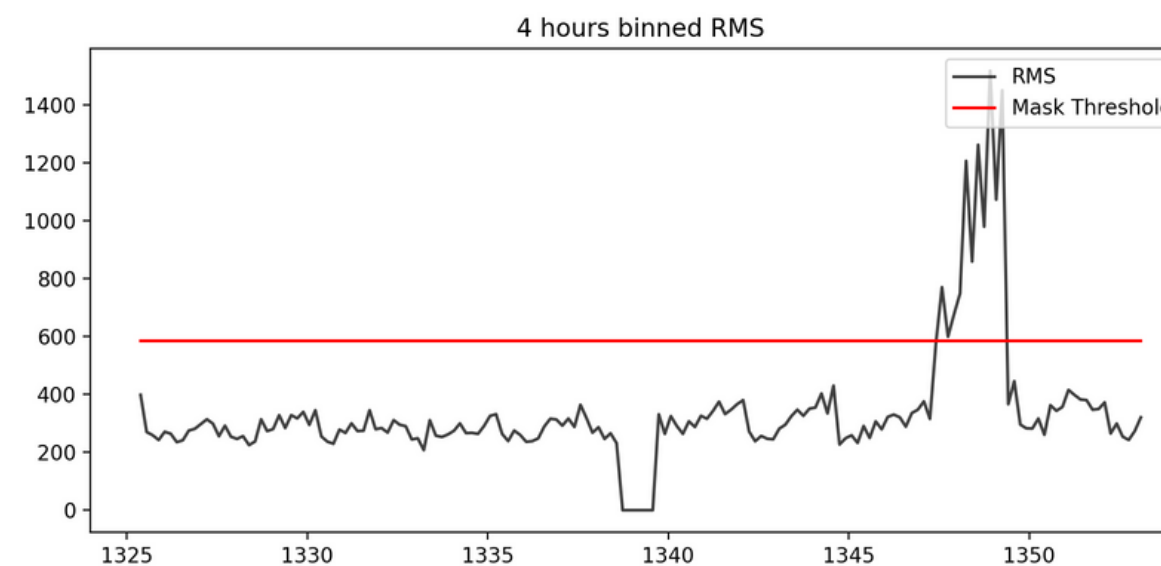


• Are there some noisy regions?

- **INITIAL_HIGH_RMS_MASK: TRUE / FALSE**
- **INITIAL_HIGH_RMS_THRESHOLD: 1.25 - 2**

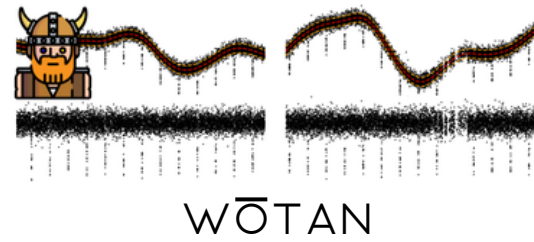
```
Abrir  explore.yaml  Guardar  -  x
~/Escritorio/EXOPLANETAS...

1 TARGETS:
2 TIC xxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```



The six SHERLOCK modules

Lightkurve



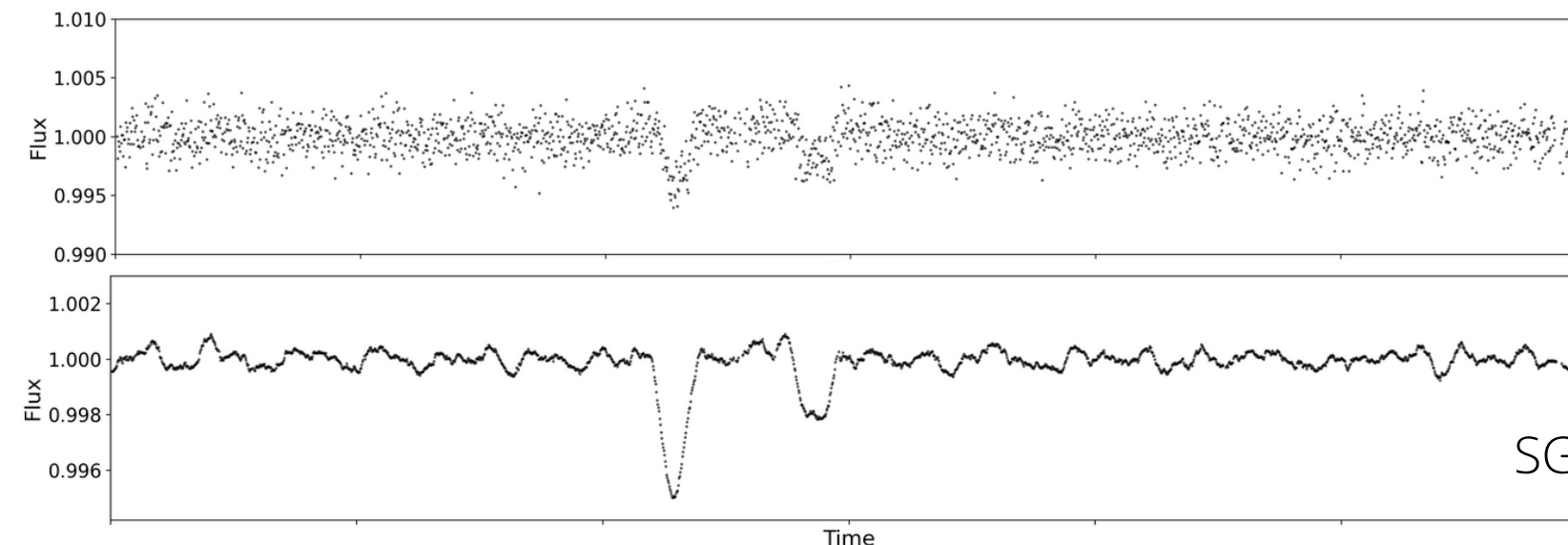
(1)

Prepare the data

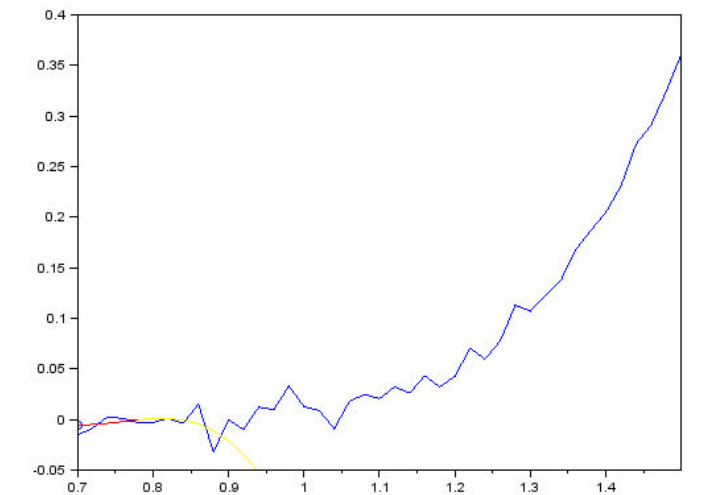
```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

```
Abrir explore.yaml ~/Escritorio/EXOPLANETAS... Guardar
1 TARGETS:
2 TIC xxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```

• INITIAL_SMOOTH_ENABLE: TRUE/FALSE



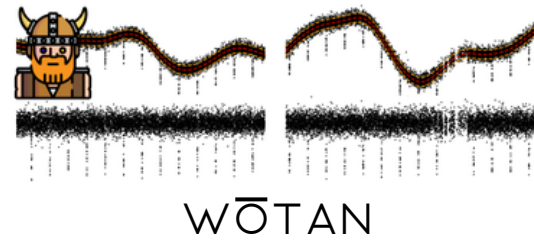
Savitsky-Golay filter



Similar SDEs but increase the SNR significantly!

The six SHERLOCK modules

Lightkurve



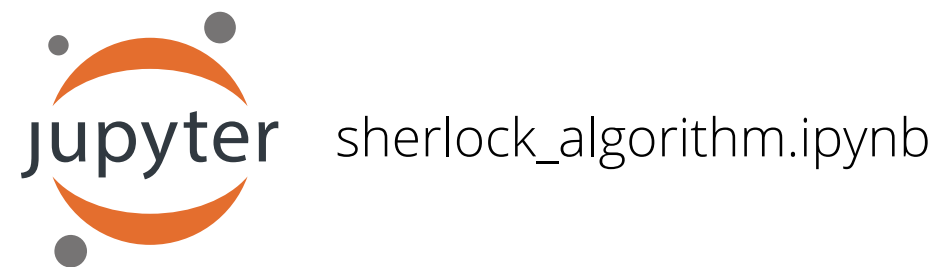
(1)

Prepare the data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

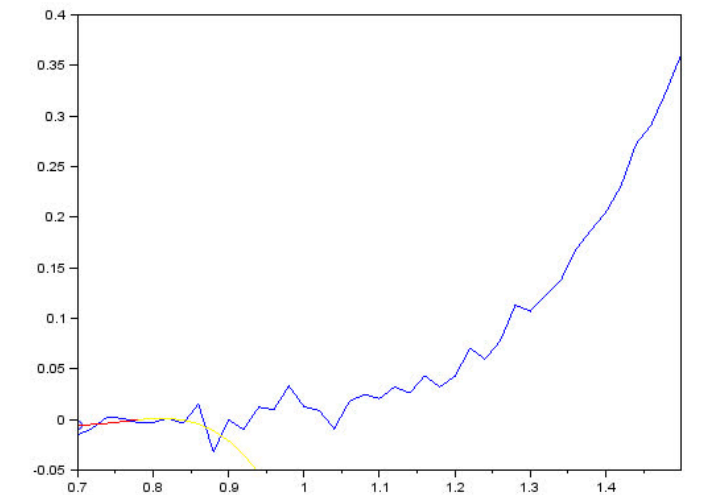
```
Abrir explore.yaml ~/Escritorio/EXOPLANETAS... Guardar
1 TARGETS:
2 TIC xxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```

• INITIAL_SMOOTH_ENABLE: TRUE/FALSE



Savitsky-Golay filter

SG



Similar SDEs but increase the SNR significantly!

The six SHERLOCK modules



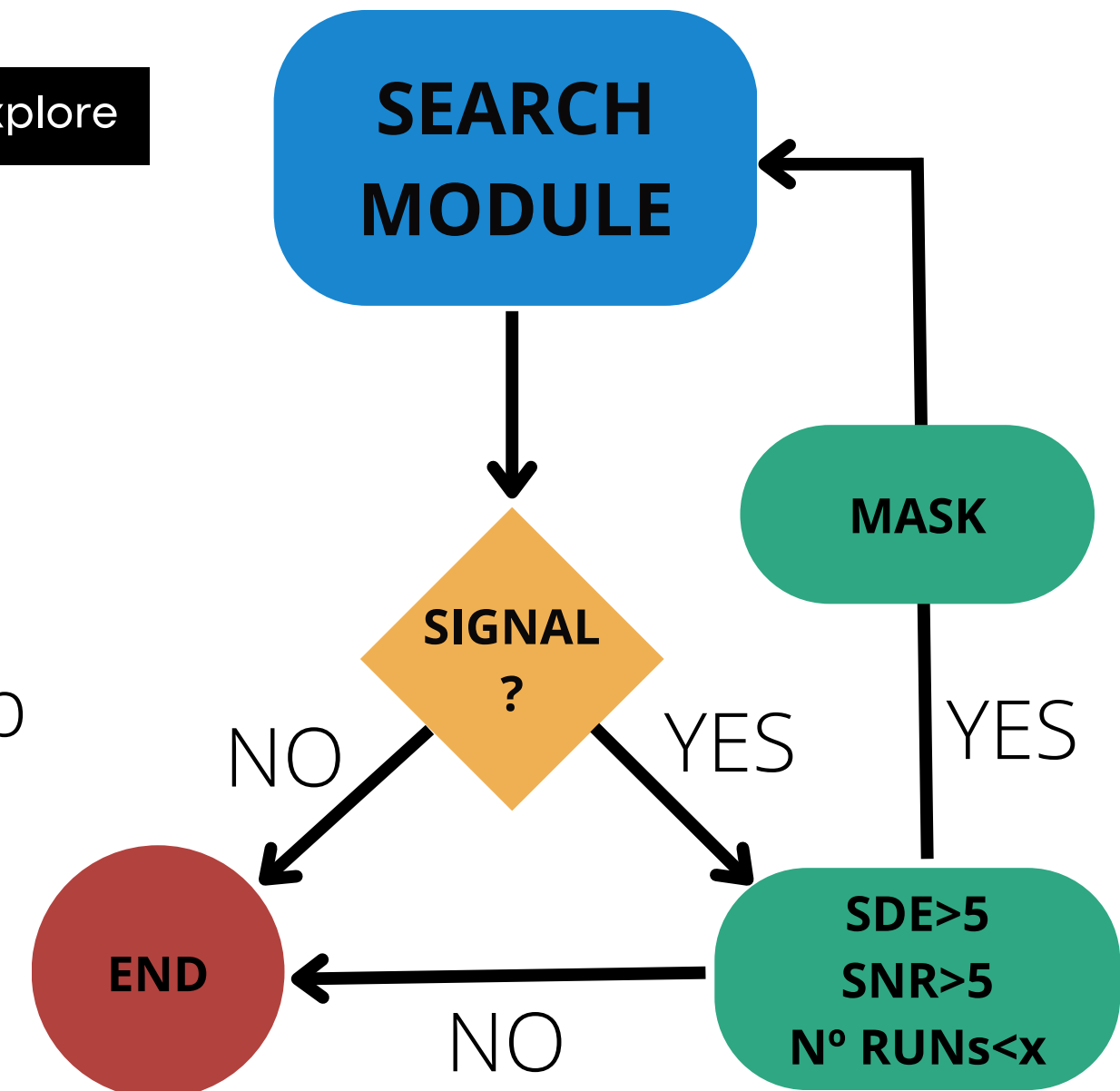
(1)
Prepare the data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

```
1 TARGETS:
2 TIC xxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```

- MAX_RUNS: 1-5
- SNR_MIN: 5
- SDE_MIN: 5

Searching-and-masking loop



The six SHERLOCK modules



(1)

Prepare the data

```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

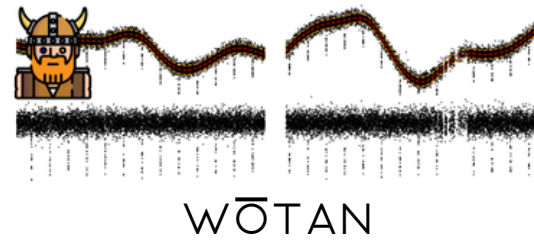


```
Abrir  explore.yaml  Guardar  -  x
~/Escritorio/EXOPLANETAS...
1 TARGETS:
2 TIC xxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```

- **DETREND_CORES:** [NUMBER OF CORES YOU WANT TO USE]
- **CPU_CORES:** [NUMBER OF CORES YOU WANT TO USE]
- **UPDATE_OIS:** TRUE/FALSE

The six SHERLOCK modules

Lightkurve



(1)

Prepare the data



```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

```
Abrir  explore.yaml  Guardar  -  x
~/Escritorio/EXOPLANETAS...
1 TARGETS:
2 TIC xxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
21
22
```

- **DETREND_CORES:** [NUMBER OF CORES YOU WANT TO USE]
- **CPU_CORES:** [NUMBER OF CORES YOU WANT TO USE]
- **UPDATE_OIS:** TRUE/FALSE

AND MANY MORE...

https://github.com/iaa-so-training/sherlock-tutorial/blob/main/Yaml_examples/properties.yaml

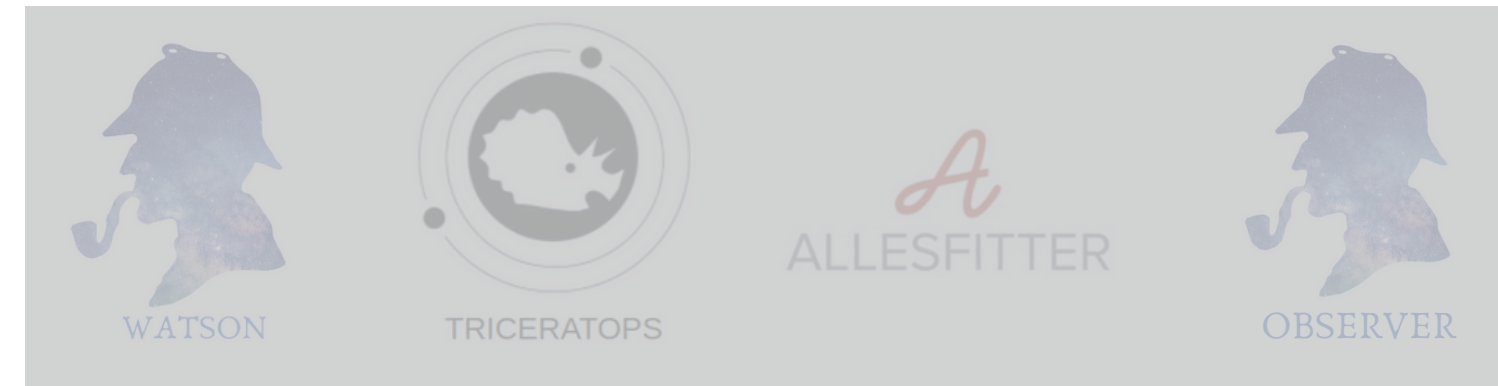
The six SHERLOCK modules



Transit Least
Squares

(2)

Search for
candidates

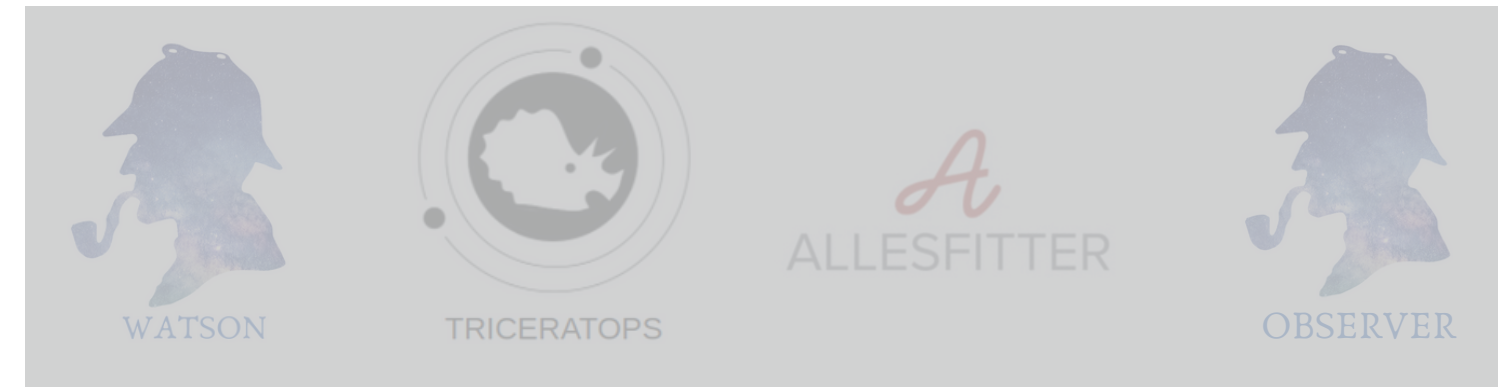


```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

The six SHERLOCK modules



Transit Least Squares



(2)

Search for candidates

```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

```
1 TARGETS:
2 TIC 259377017:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2
15 SNR_MIN: 5
16 SDE_MIN: 5
17 PERIOD_MIN: 1
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
```

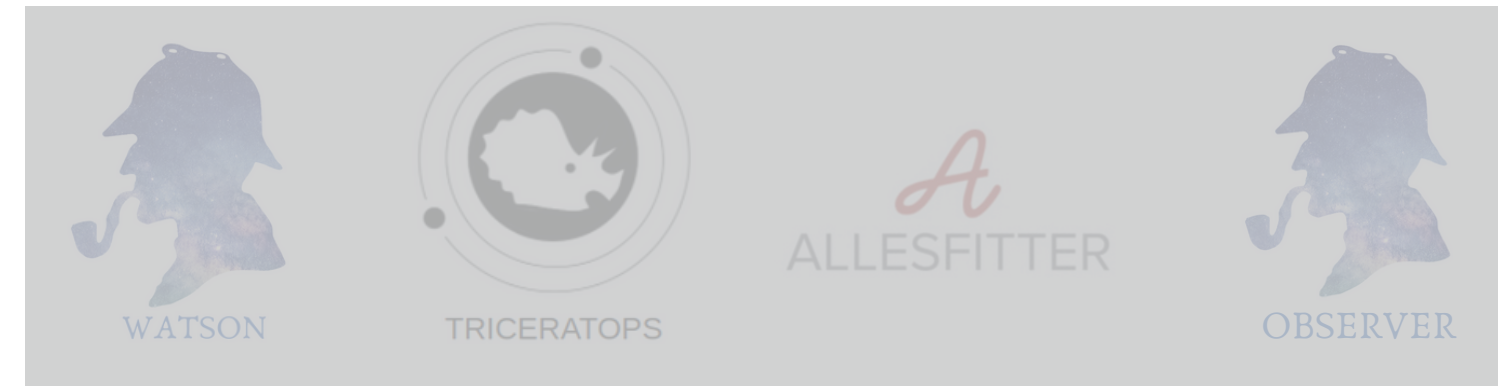


```
1 TARGETS:
2 TIC 259377017:
3 MODE: GLOBAL
4 SECTORS: [3,4,5]
5 AUTO_DETREND_ENABLED: False
6 INITIAL_HIGH_RMS_MASK: False
7 INITIAL_SMOOTH_ENABLED: True
8 INITIAL_HIGH_RMS_THRESHOLD: 2.0
9 EXPTIME: 120
10 DETREND_L_MIN: 0.2
11 DETREND_L_MAX: 1.2
12 DETRENDS_NUMBER: 10
13 DETREND_CORES: 10
14 CPU_CORES: 45
15 MAX_RUNS: 3
16 SNR_MIN: 5
17 SDE_MIN: 5
18 PERIOD_MIN: 1.0
19 PERIOD_MAX: 15
20 UPDATE_OIS: True
21
```


The six SHERLOCK modules



Transit Least Squares



(2)

Search for candidates

```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

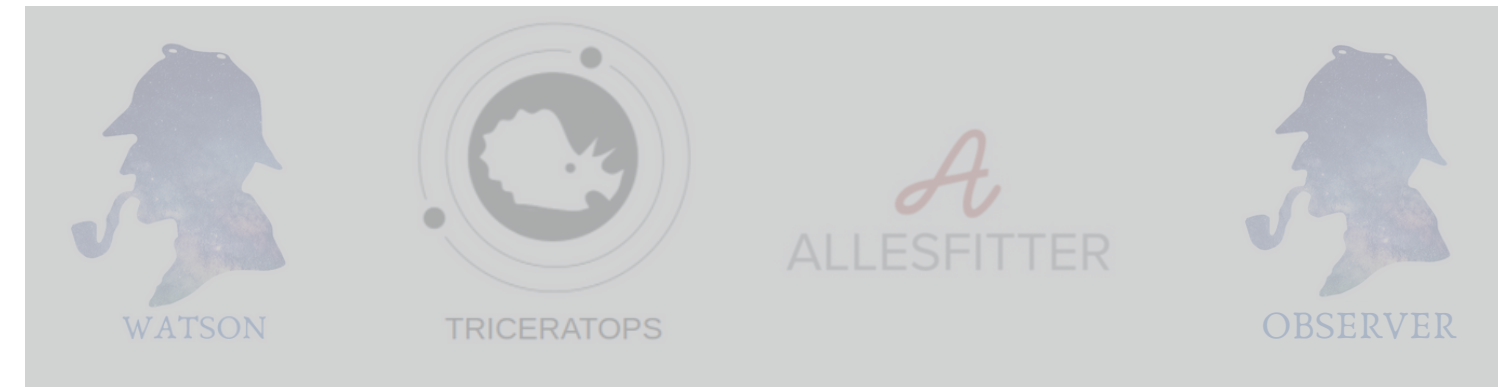
```
1 TARGETS:
2 TIC 259377017:
3   MODE: GLOBAL
4   SECTORS: [3,4,5]
5   AUTO_DETREND_ENABLED: False
6   INITIAL_HIGH_RMS_MASK: False
7   INITIAL_SMOOTH_ENABLED: True
8   INITIAL_HIGH_RMS_THRESHOLD: 2.0
9   EXPTIME: 120
10  DETREND_L_MIN: 0.2
11  DETREND_L_MAX: 1.2
12  DETRENDS_NUMBER: 10
13  DETREND_CORES: 10
14  CPU_CORES: 45
15  MAX_RUNS: 3
16  SNR_MIN: 5
17  SDE_MIN: 5
18  PERIOD_MIN: 1.0
19  PERIOD_MAX: 15
20  UPDATE_OIS: True
21
```

SHERLOCK will search for planets over the **detrended light curves + PCD_SAP**

The six SHERLOCK modules



Transit Least Squares



(2)

Search for candidates

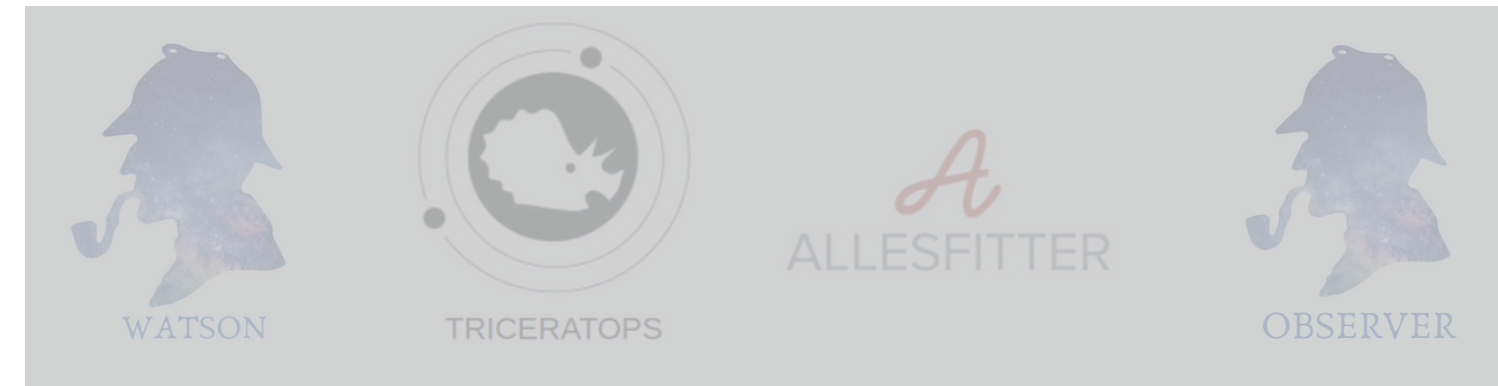
```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

```
1 TARGETS:
2 TIC 259377017:
3   MODE: GLOBAL
4   SECTORS: [3,4,5]
5   AUTO_DETREND_ENABLED: False
6   INITIAL_HIGH_RMS_MASK: False
7   INITIAL_SMOOTH_ENABLED: True
8   INITIAL_HIGH_RMS_THRESHOLD: 2.0
9   EXPTIME: 120
10  DETREND_L_MIN: 0.2
11  DETREND_L_MAX: 1.2
12  DETRENDS_NUMBER: 10
13  DETREND_CORES: 10
14  CPU_CORES: 45
15  MAX_RUNS: 3
16  SNR_MIN: 5
17  SDE_MIN: 5
18  PERIOD_MIN: 1.0
19  PERIOD_MAX: 15
20  UPDATE_OIS: True
21
```

SHERLOCK will search for planets over the **detrended light curves + PCD_SAP**

→ 10+1 !!

The six SHERLOCK modules



(2)

Search for candidates

```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

```
1 TARGETS:
2 TIC 259377017:
3   MODE: GLOBAL
4   SECTORS: [3,4,5]
5   AUTO_DETREND_ENABLED: False
6   INITIAL_HIGH_RMS_MASK: False
7   INITIAL_SMOOTH_ENABLED: True
8   INITIAL_HIGH_RMS_THRESHOLD: 2.0
9   EXPTIME: 120
10  DETREND_L_MIN: 0.2
11  DETREND_L_MAX: 1.2
12  DETRENDS_NUMBER: 10
13  DETREND_CORES: 10
14  CPU_CORES: 45
15  MAX_RUNS: 3
16  SNR_MIN: 5
17  SDE_MIN: 5
18  PERIOD_MIN: 1.0
19  PERIOD_MAX: 15
20  UPDATE_OIS: True
21
```

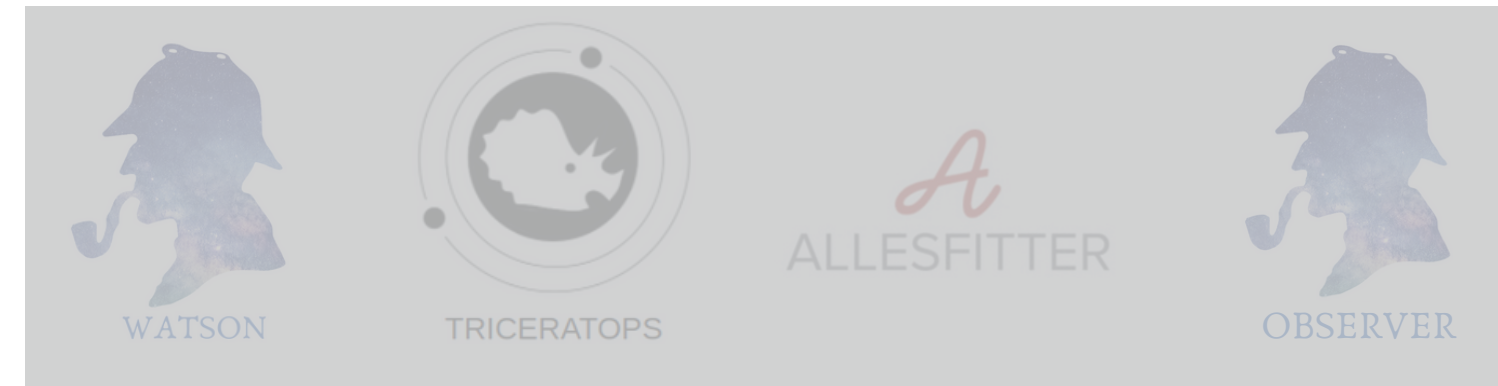
SHERLOCK will search for planets over the **detrended light curves + PCD_SAP**



The six SHERLOCK modules



Transit Least Squares



(2)

Search for candidates

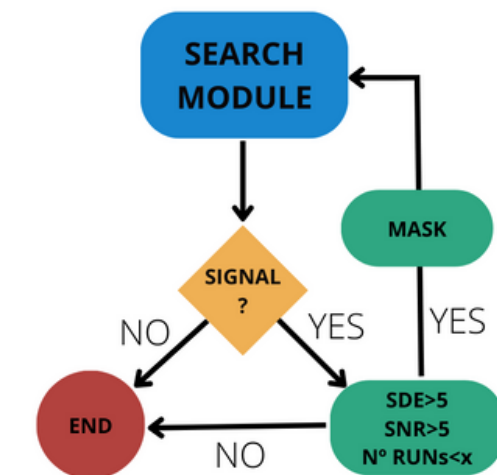
```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

```
1 TARGETS:
2 TIC 259377017:
3 MODE: GLOBAL
4 SECTORS: [3,4,5]
5 AUTO_DETREND_ENABLED: False
6 INITIAL_HIGH_RMS_MASK: False
7 INITIAL_SMOOTH_ENABLED: True
8 INITIAL_HIGH_RMS_THRESHOLD: 2.0
9 EXPTIME: 120
10 DETREND_L_MIN: 0.2
11 DETREND_L_MAX: 1.2
12 DETRENDS_NUMBER: 10
13 DETREND_CORES: 10
14 CPU_CORES: 45
15 MAX_RUNS: 3
16 SNR_MIN: 5
17 SDE_MIN: 5
18 PERIOD_MIN: 1.0
19 PERIOD_MAX: 15
20 UPDATE_OIS: True
21
```

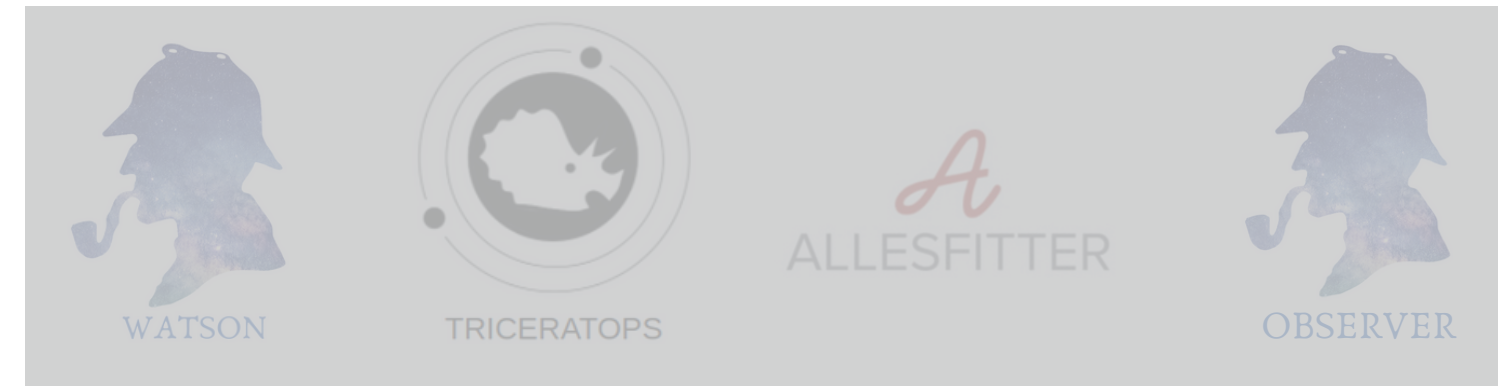
3 !!

SHERLOCK will search for planets over the **detrended light curves + PCD_SAP** a number of times

Searching-and-masking loop



The six SHERLOCK modules



(2)

Search for candidates

```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

```
1 TARGETS:
2 TIC 259377017:
3   MODE: GLOBAL
4   SECTORS: [3,4,5]
5   AUTO_DETREND_ENABLED: False
6   INITIAL_HIGH_RMS_MASK: False
7   INITIAL_SMOOTH_ENABLED: True
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13  DETREND_CORES: 10
14  CPU_CORES: 45
15  MAX_RUNS: 3
16  SNR_MIN: 5
17  SDE_MIN: 5
18  PERIOD_MIN: 1.0
19  PERIOD_MAX: 15
20  UPDATE_OIS: True
21
```

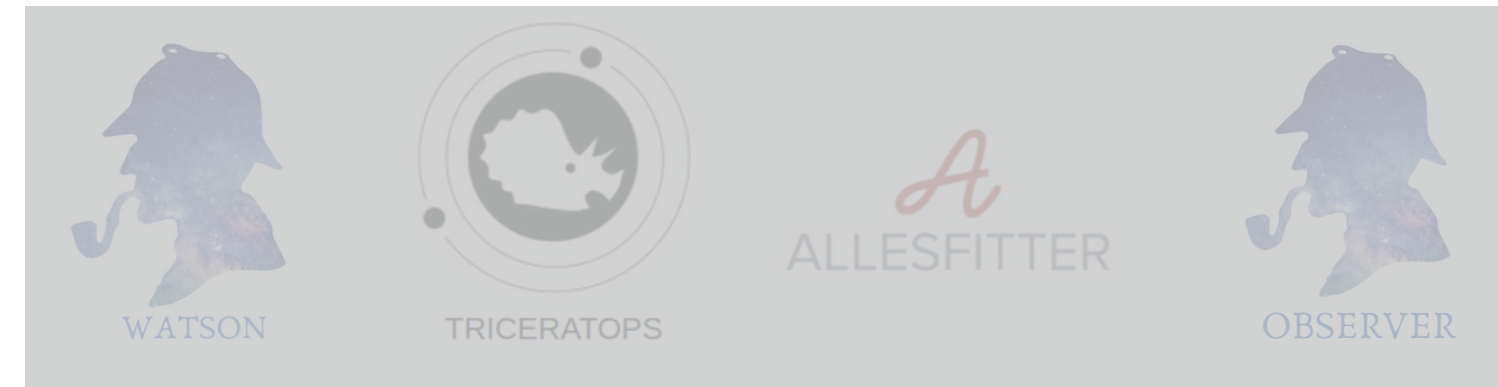
SHERLOCK will search for planets over the **detrended light curves + PCD_SAP** a number of times



The six SHERLOCK modules



Transit Least Squares

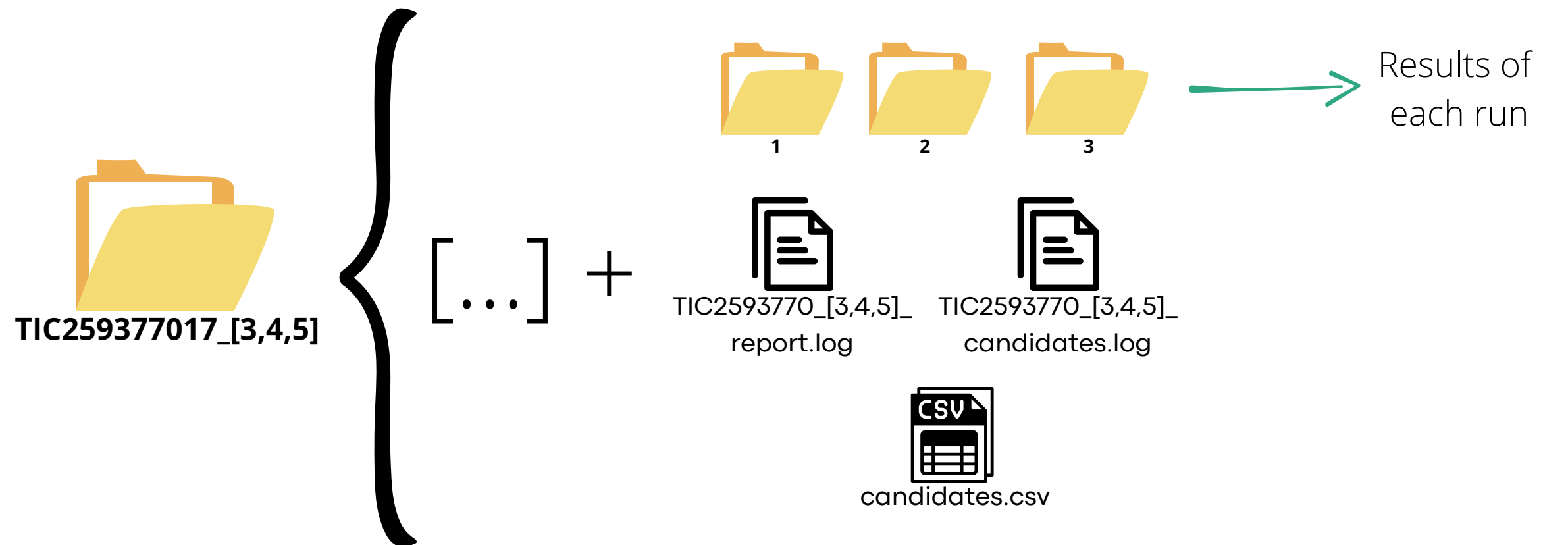


(2)

Search for candidates

```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

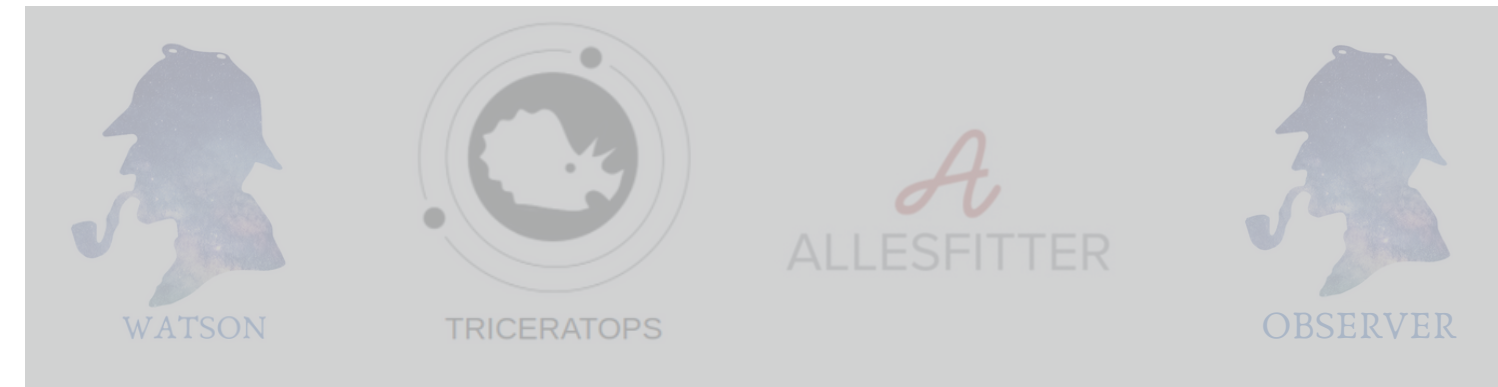
```
1 TARGETS:  
2 TIC 259377017:  
3 MODE: GLOBAL  
4 SECTORS: [3,4,5]  
5 AUTO_DETREND_ENABLED: False  
6 INITIAL_HIGH_RMS_MASK: False  
7 INITIAL_SMOOTH_ENABLED: True  
8 INITIAL_HIGH_RMS_THRESHOLD: 2.0  
9 DETREND_L_MIN: 0.2  
10 DETREND_L_MAX: 1.2  
11 DETRENDS_NUMBER: 10  
12 DETREND_CORES: 10  
13 CPU_CORES: 45  
14 MAX_RUNS: 3  
15 SNR_MIN: 5  
16 SDE_MIN: 5  
17 PERIOD_MIN: 1.0  
18 PERIOD_MAX: 15  
19 UPDATE_OIS: True  
20
```



The six SHERLOCK modules



Transit Least Squares



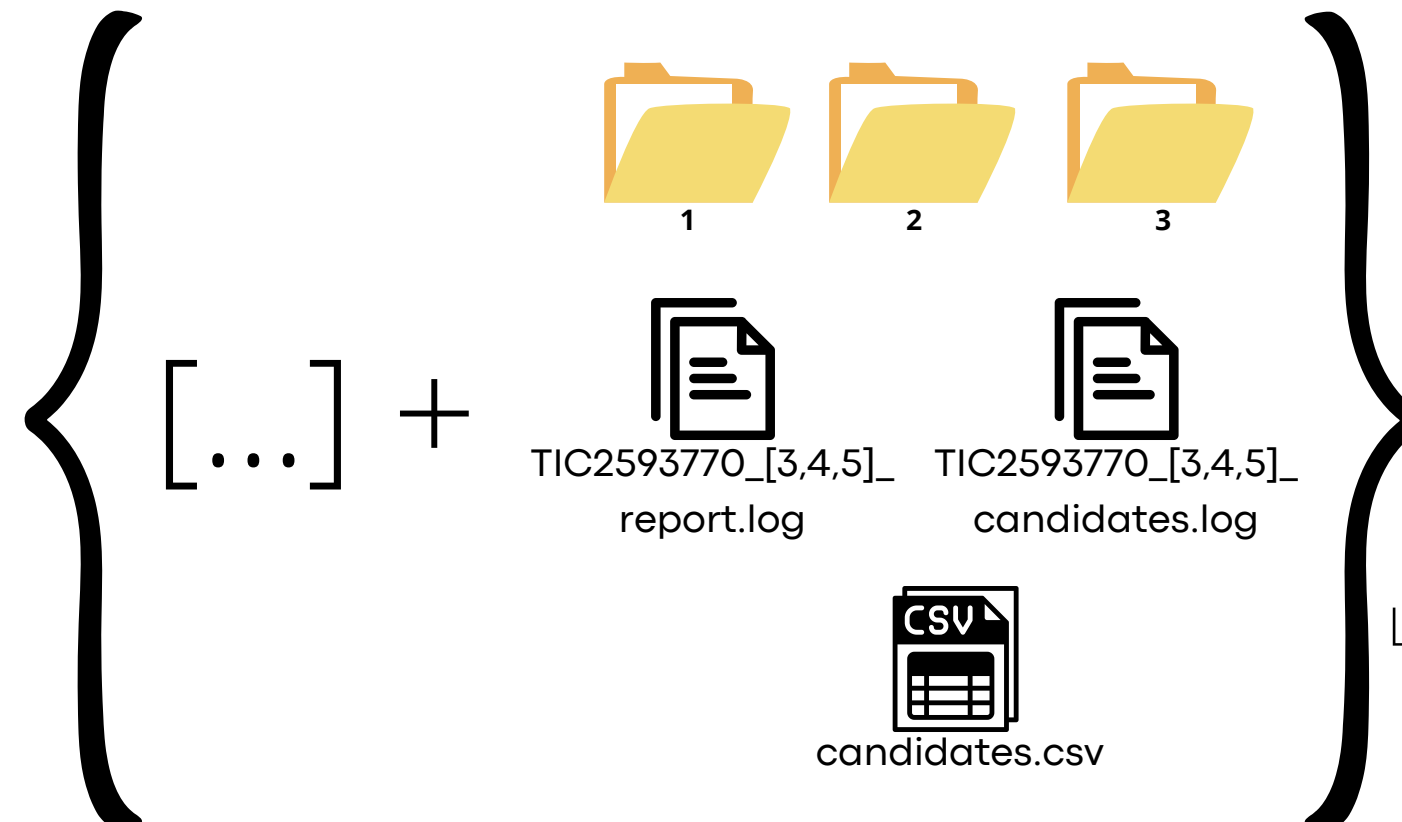
(2)

Search for candidates

```
python3.10 -m sherlockpipe --properties xxxxx.yaml
```

```
1 TARGETS:
2 TIC 259377017:
3   MODE: GLOBAL
4   SECTORS: [3,4,5]
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9   DETREND_L_MIN: 0.2
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11  DETRENDS_NUMBER: 10
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14  MAX_RUNS: 3
15  SNR_MIN: 5
16  SDE_MIN: 5
17  PERIOD_MIN: 1.0
18  PERIOD_MAX: 15
19  UPDATE_OIS: True
20
```

TIC259377017_[3,4,5]



Have a quick look at the results!

- Transit shape?
- Border score?
- Persistent signal?

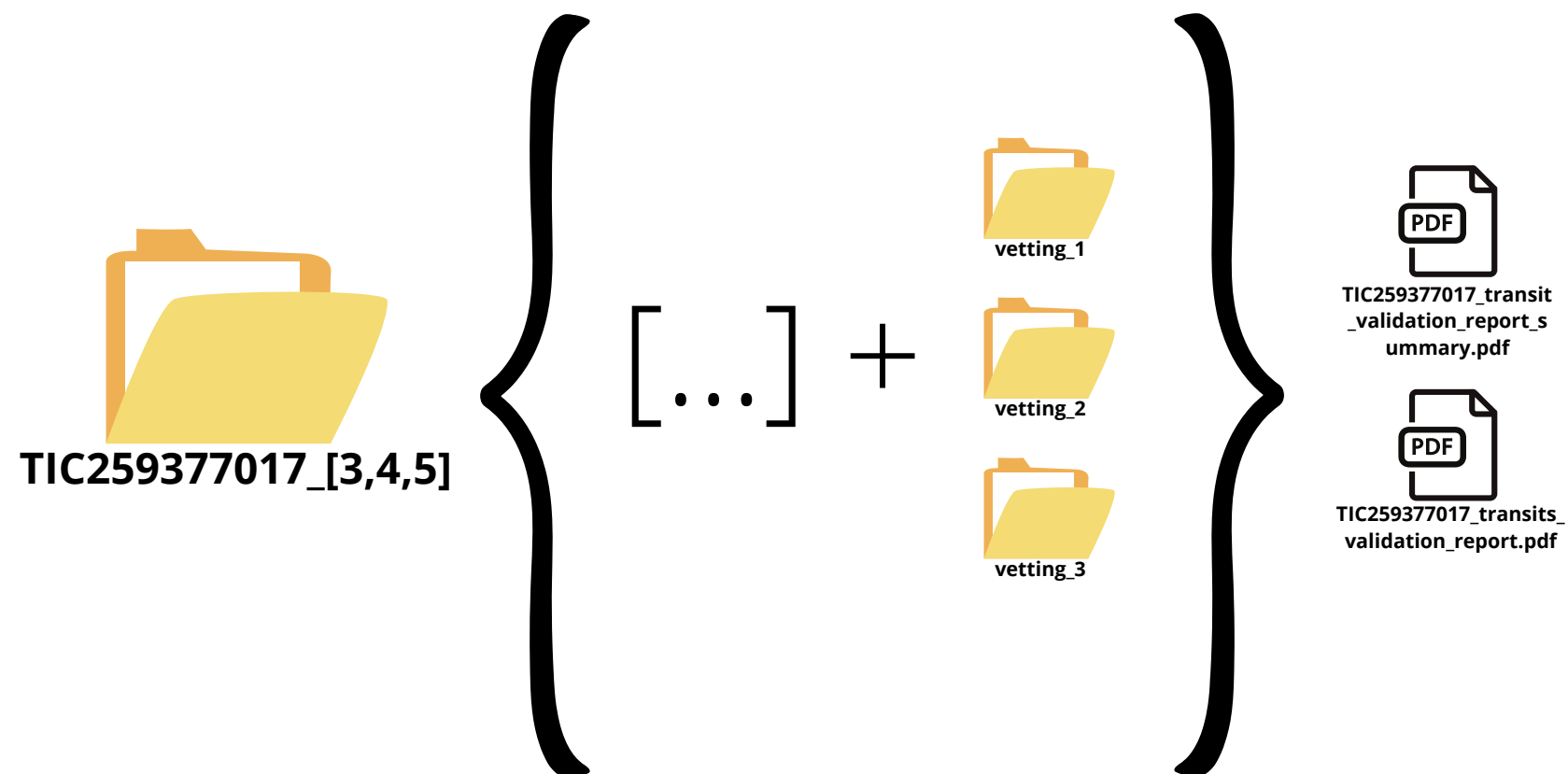
Let's explore the files y together!

The six SHERLOCK modules



```
python3.10 -m sherlockpipe.vet --candidate x
```

x=1, 2, 3 ...



- Are the transit depths consistent?
- Where is the signal produced in the tpf?
- How do the harmonics look like?
- How does each individual transit look like?
- May any systematic be producing the signal?
- Which is the field-of-view?

Let's explore the files y
together!

The six SHERLOCK modules

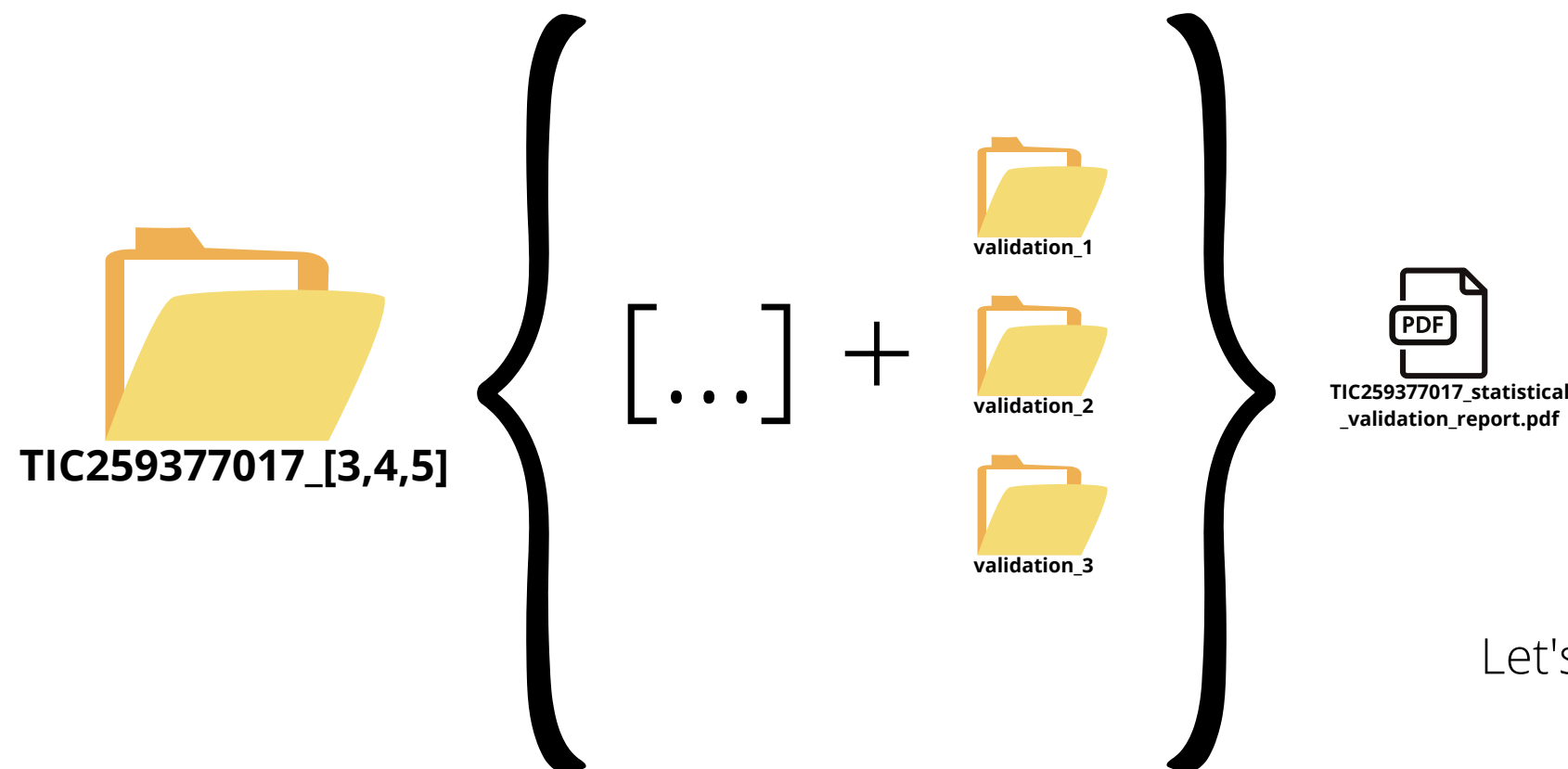


```
python3.10 -m sherlockpipe.validate --candidate x
```

x=1, 2, 3 ...

(4)
Statistical
validation

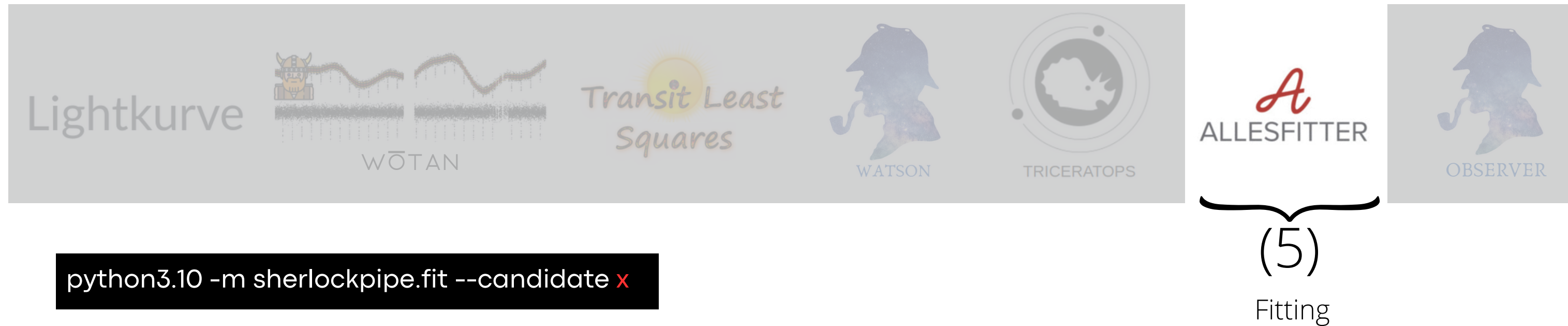
- Is there any other astrophysical scenario producing the signal?



Let's explore the files y together!

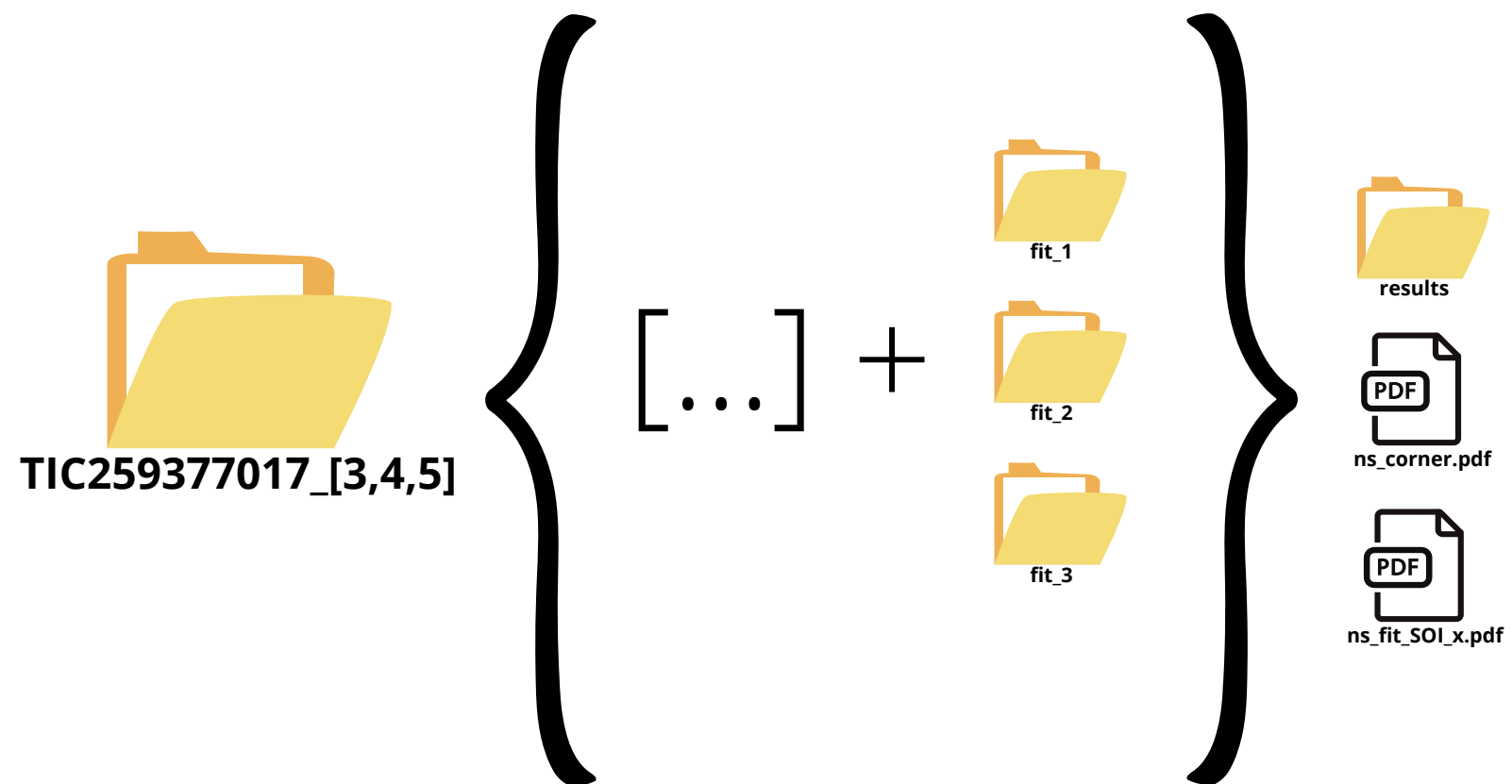
Scenarios Tested by TRICERATOPS	
Scenario	Configuration
TP	No unresolved companion; transiting planet with P_{orb} around target star
EB	No unresolved companion; eclipsing binary with P_{orb} around target star
EBx2P	No unresolved companion; eclipsing binary with $2 \times P_{orb}$ around target star
PTP	Unresolved bound companion; transiting planet with P_{orb} around primary star
PEB	Unresolved bound companion; eclipsing binary with P_{orb} around primary star
PEBx2P	Unresolved bound companion; eclipsing binary with $2 \times P_{orb}$ around primary star
STP	Unresolved bound companion; transiting planet with P_{orb} around secondary star
SEB	Unresolved bound companion; eclipsing binary with P_{orb} around secondary star
SEBx2P	Unresolved bound companion; eclipsing binary with $2 \times P_{orb}$ around secondary star
DTP	Unresolved background star; transiting planet with P_{orb} around target star
DEB	Unresolved background star; eclipsing binary with P_{orb} around target star
DEBx2P	Unresolved background star; eclipsing binary with $2 \times P_{orb}$ around target star
BTP	Unresolved background star; transiting planet with P_{orb} around background star
BEB	Unresolved background star; eclipsing binary with P_{orb} around background star
BEBx2P	Unresolved background star; eclipsing binary with $2 \times P_{orb}$ around background star
NTP	No unresolved companion; transiting planet with P_{orb} around nearby star
NEB	No unresolved companion; eclipsing binary with P_{orb} around nearby star
NEBx2P	No unresolved companion; eclipsing binary with $2 \times P_{orb}$ around nearby star

The six SHERLOCK modules



```
python3.10 -m sherlockpipe.fit --candidate x
```

x=1, 2, 3 ...



Predicted transit time Epoch n° cycles orbital period

$$T_c = T_0 + n \cdot P$$

$$\Delta T = \sqrt{\Delta T_0^2 + (n \cdot \Delta P)^2}$$

Let's explore the files y together!

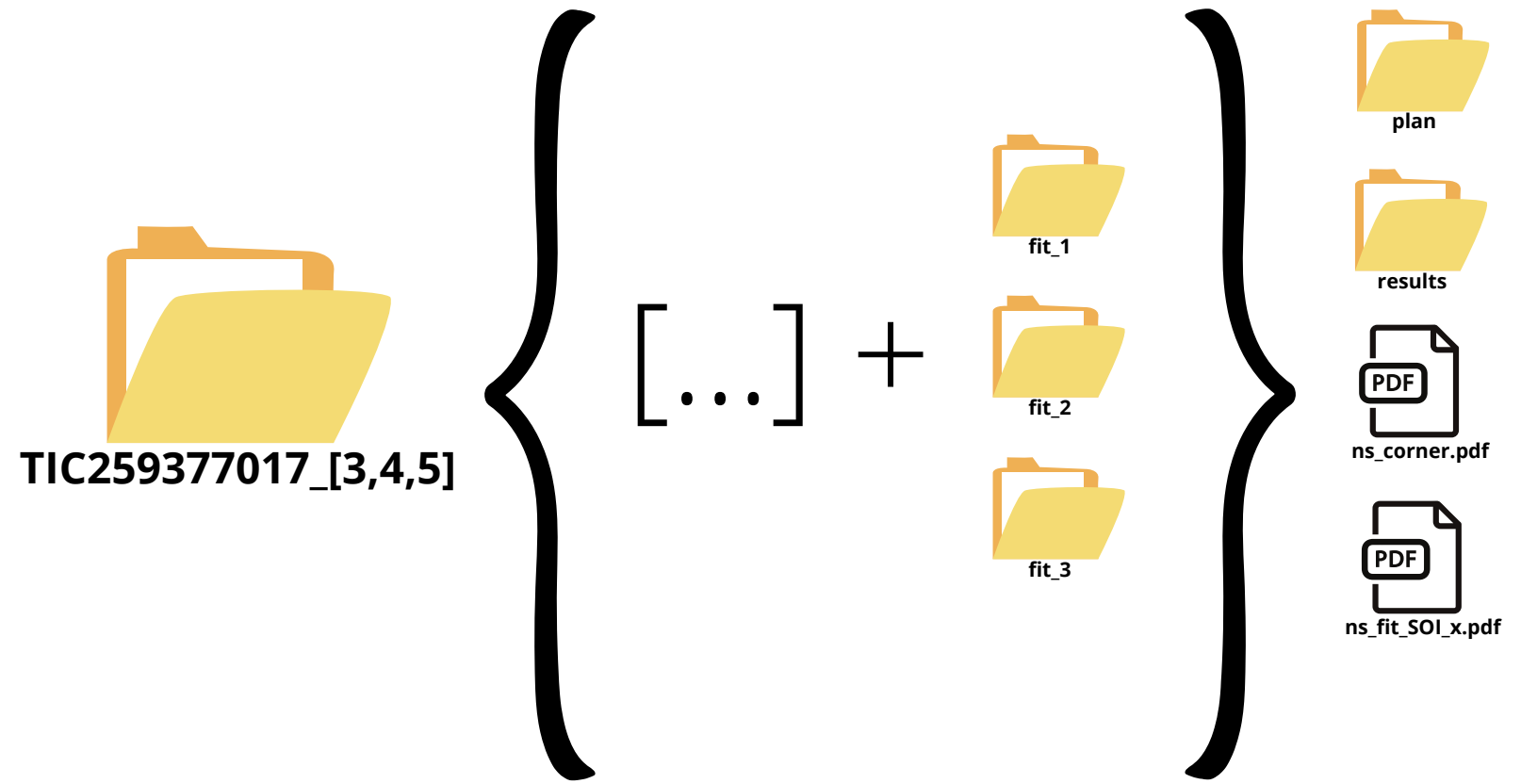
The six SHERLOCK modules



```
python3.10 -m sherlockpipe.plan --observatories observatories.csv
```

(6)
Observation
plan

List of the observatories from where you would like to observe the candidate



Let's explore the files y together!

Examples of scientific cases



SPECUL●S



(III) Examples


- Jupyter Notebooks
- A fast rotator: TOI-540
- A multiplanetary system: TOI-270
- A false positive: TOI-5747




Jupyter Notebooks

 tess_lightcurves.ipynb

 detrending_lightcurves.ipynb **EXTRA!**

 sherlock_algorithm.ipynb

 shearching_planets.ipynb **EXTRA!**

 shearching_masking.ipynb **EXTRA!**

Full Examples

 A multi-planetary system: [TOI-270](#)

 A fast rotator: [TOI-540](#)

 A false positive: [TOI-5747](#)

Take home message

Take home message



End-to-End pipeline

Take home message



End-to-End pipeline



Can be used for any transiting planet search

Take home message



End-to-End pipeline



Can be used for any transiting planet search



You only need to execute 6 command lines

Take home message



End-to-End pipeline



Can be used for any transiting planet search



You only need to execute 6 command lines



Is designed to run on a computational server

Take home message



End-to-End pipeline



Can be used for any transiting planet search



You only need to execute 6 command lines



Is designed to run on a computational server



Strong support and a Slack channel for help



THANKS !