

The SHERLOCK PIPEline

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

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(IAA-CSIC)



INSTITUTO DE
ASTROFÍSICA DE
ANDALUCÍA



EXCELENCIA
SEVERO
OCHOA



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

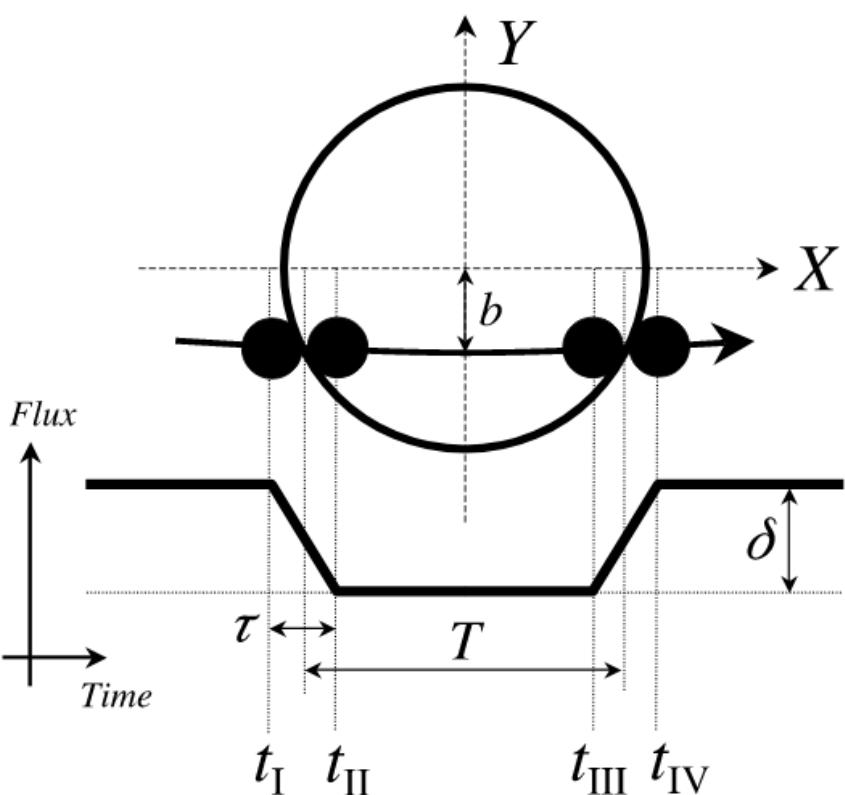
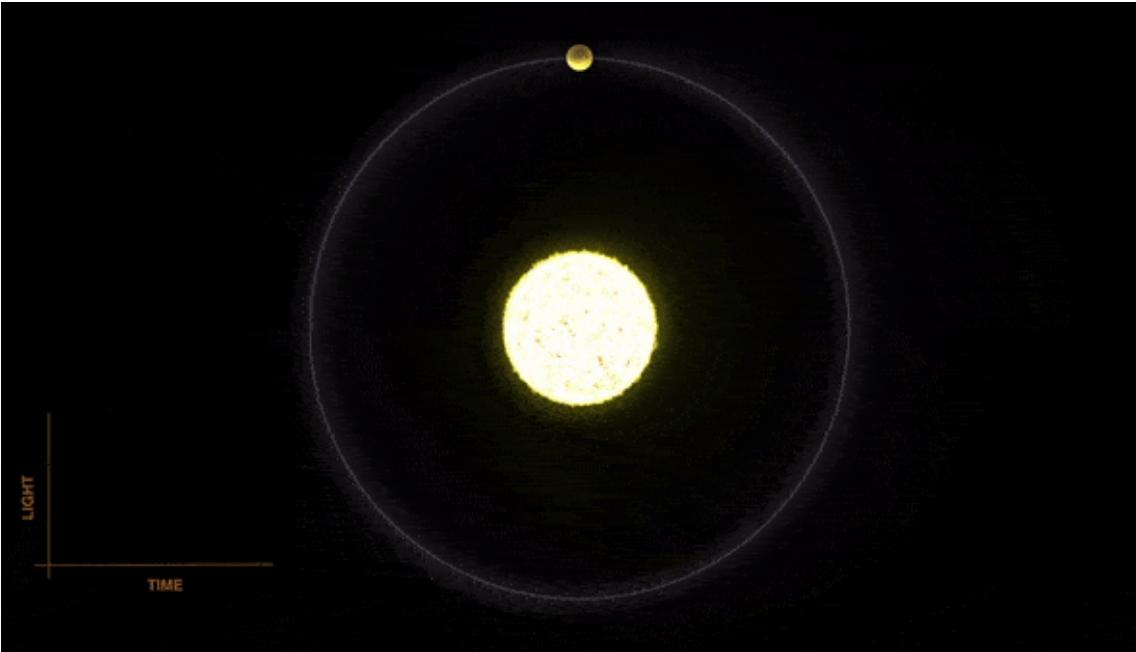
- Jupyter Notebooks
- A fast rotator: TOI-540
- A multiplanetary system: TOI-270
- A false positive: TOI-5747

(I) General overview

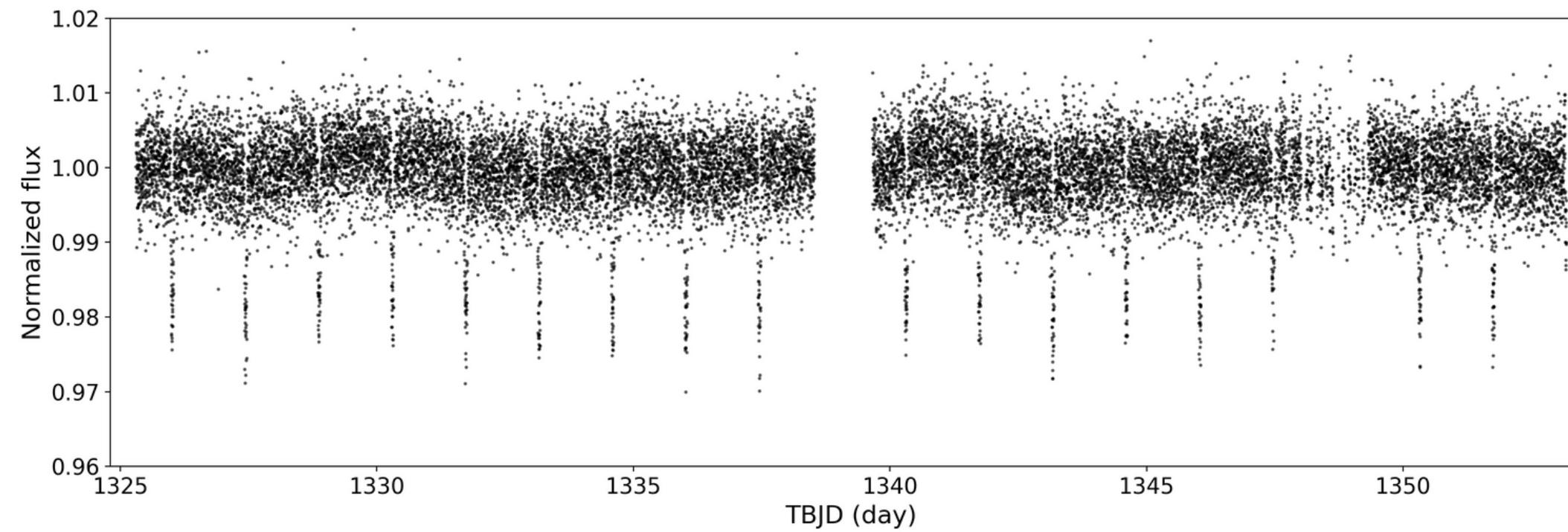
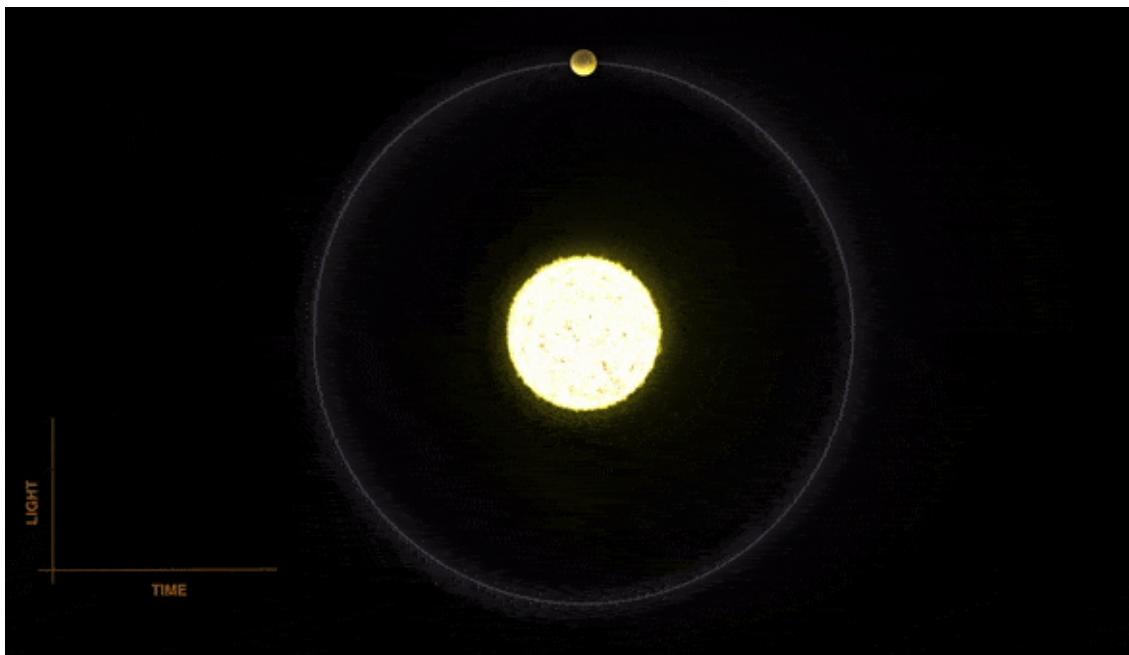
- How to search for planets in photometric data?
- TESS mission
- Why SHERLOCK?



How to search for planets in photometric data?

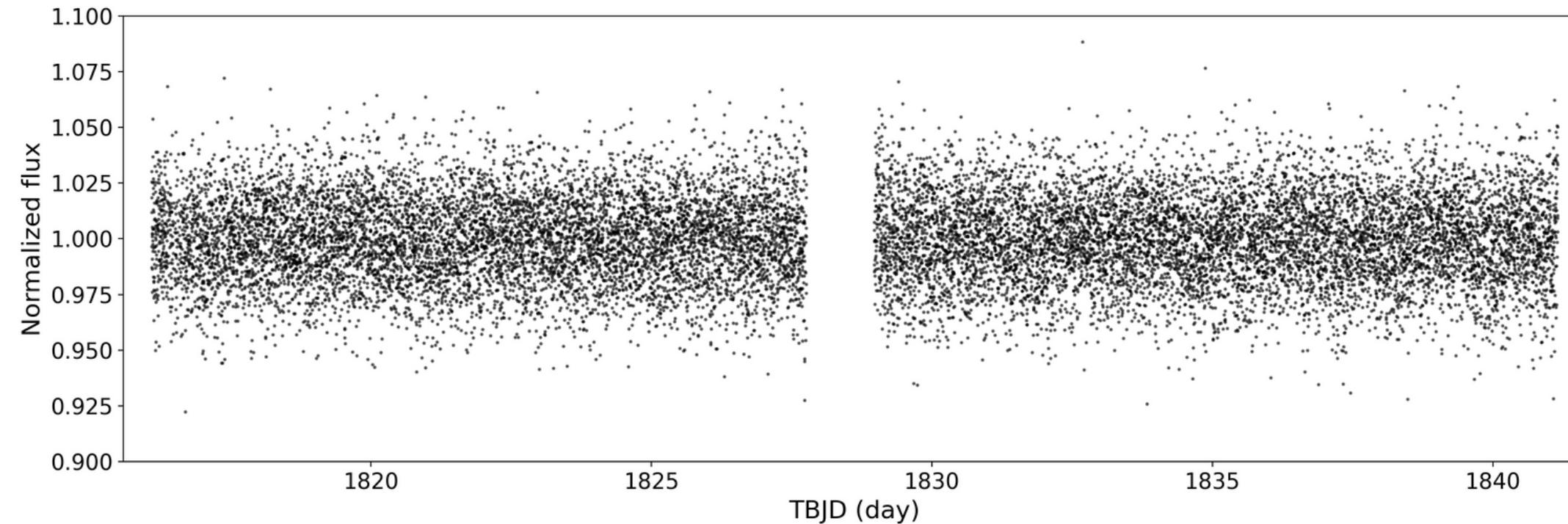
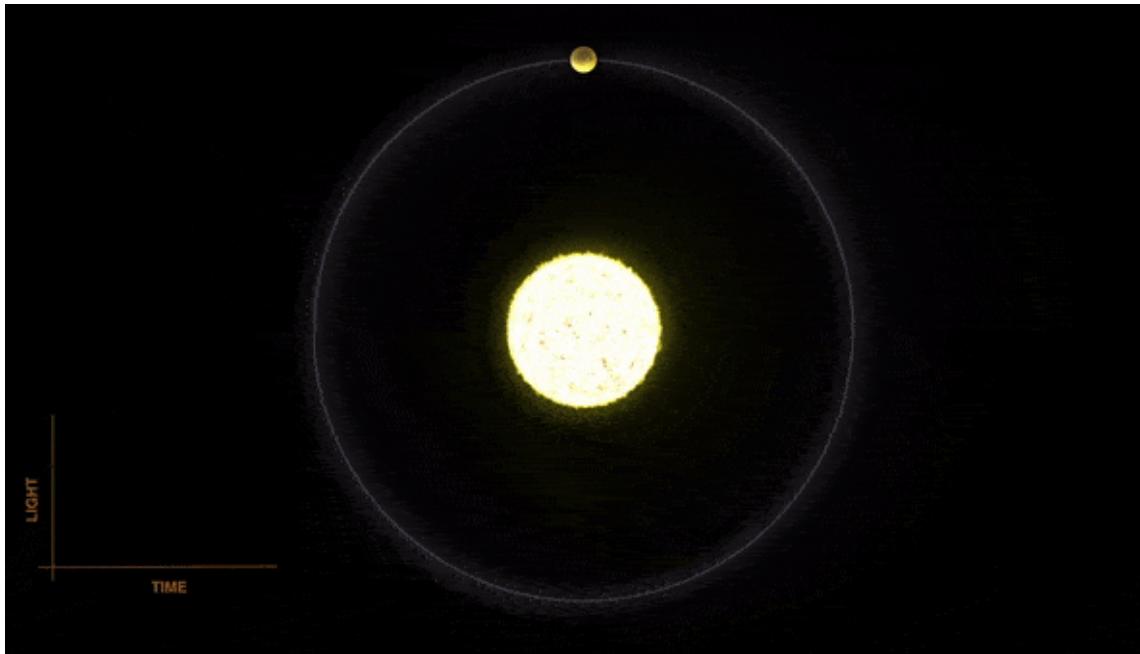


How to search for planets in photometric data?



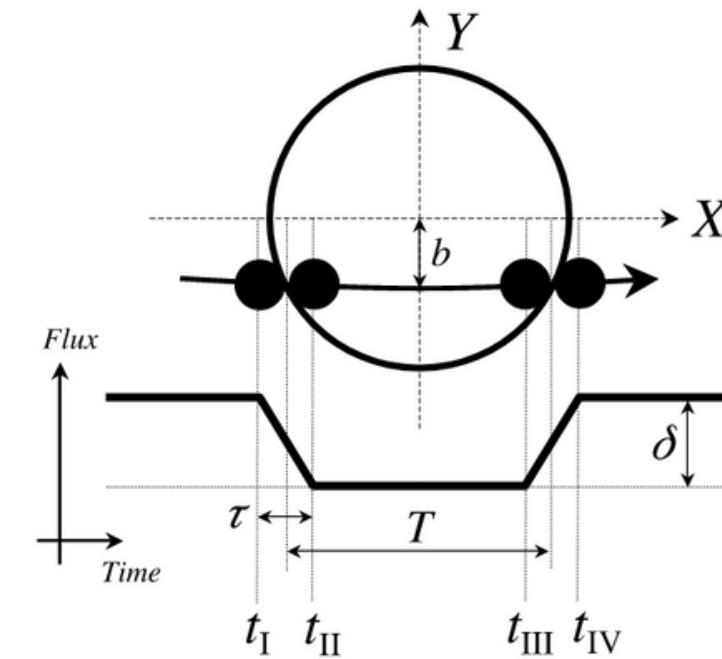
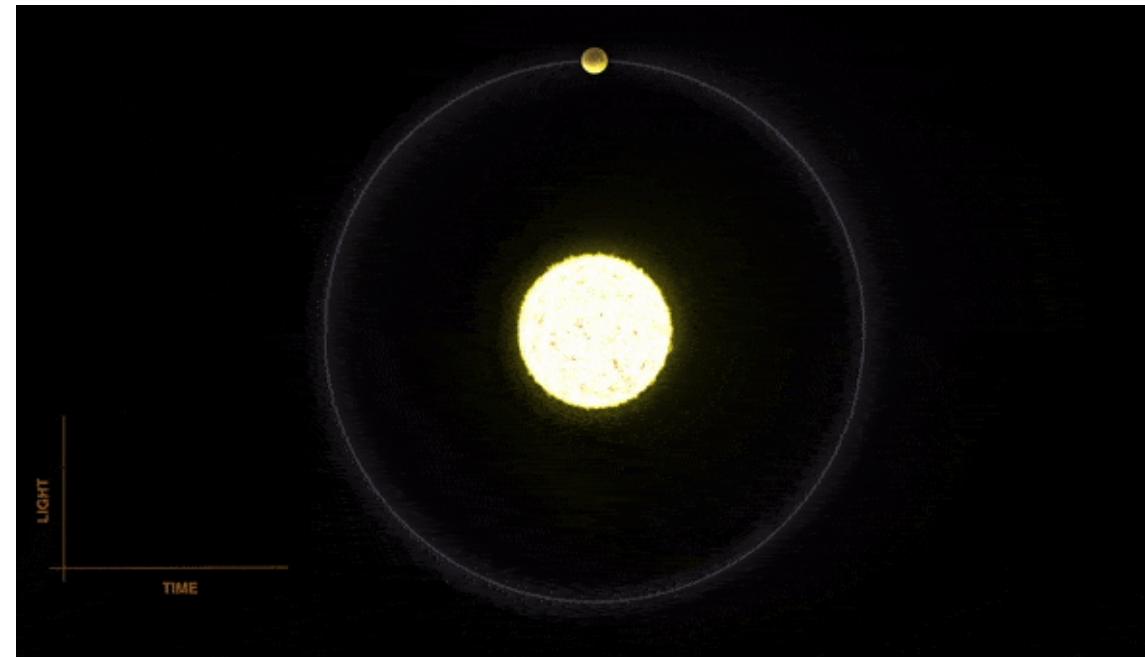
| TOI | Period (days) | Radius (R_{\oplus}) |
|--------|---------------|-------------------------|
| 101.01 | 1.43 | 13.25 |

How to search for planets in photometric data?



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

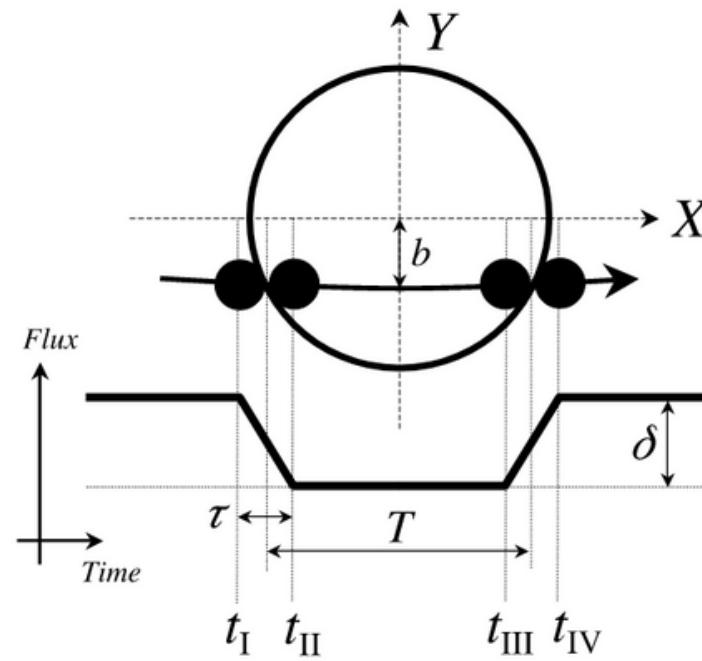
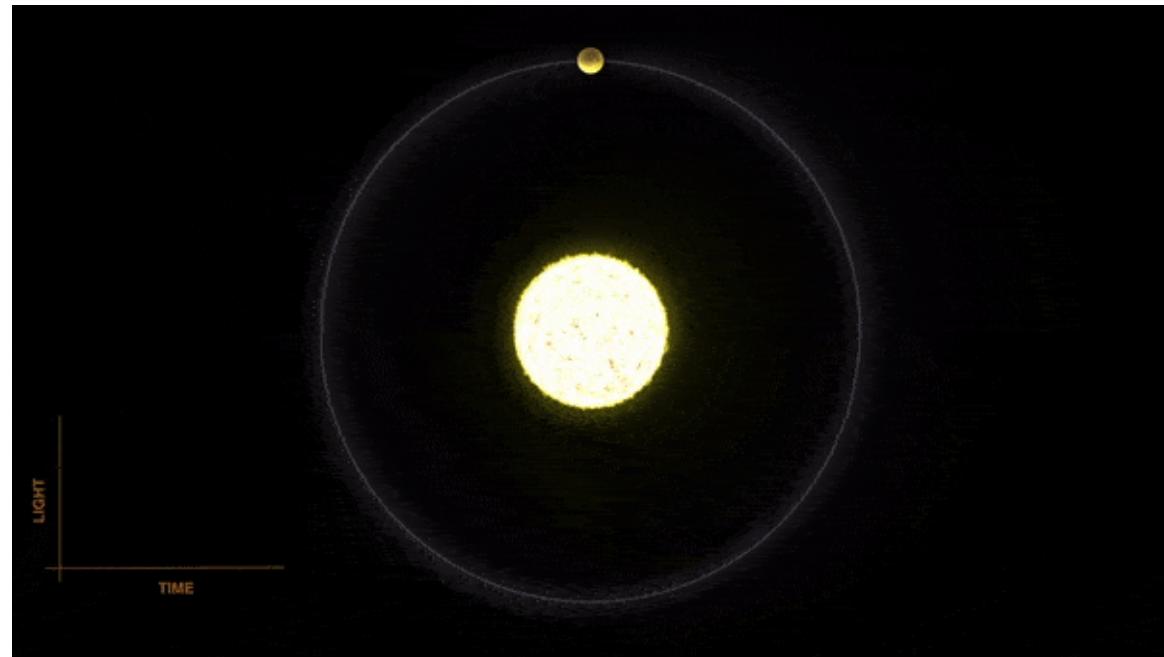
How to search for planets in photometric data?



Template transits using a range of:

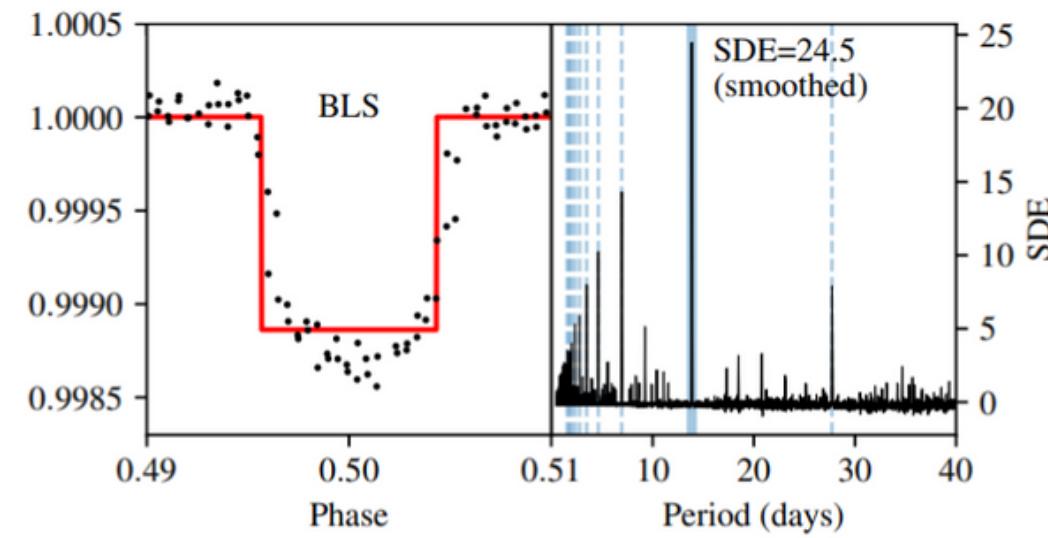
- periods
- depths
- durations

How to search for planets in photometric data?



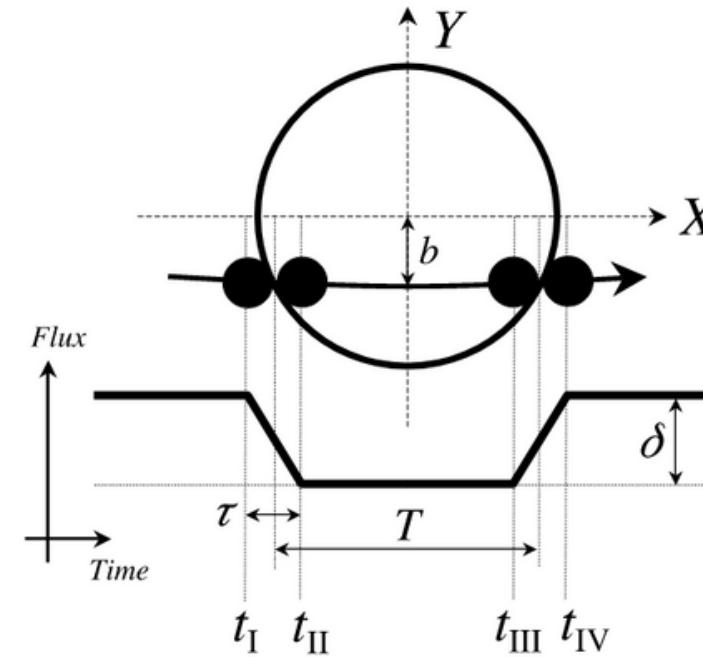
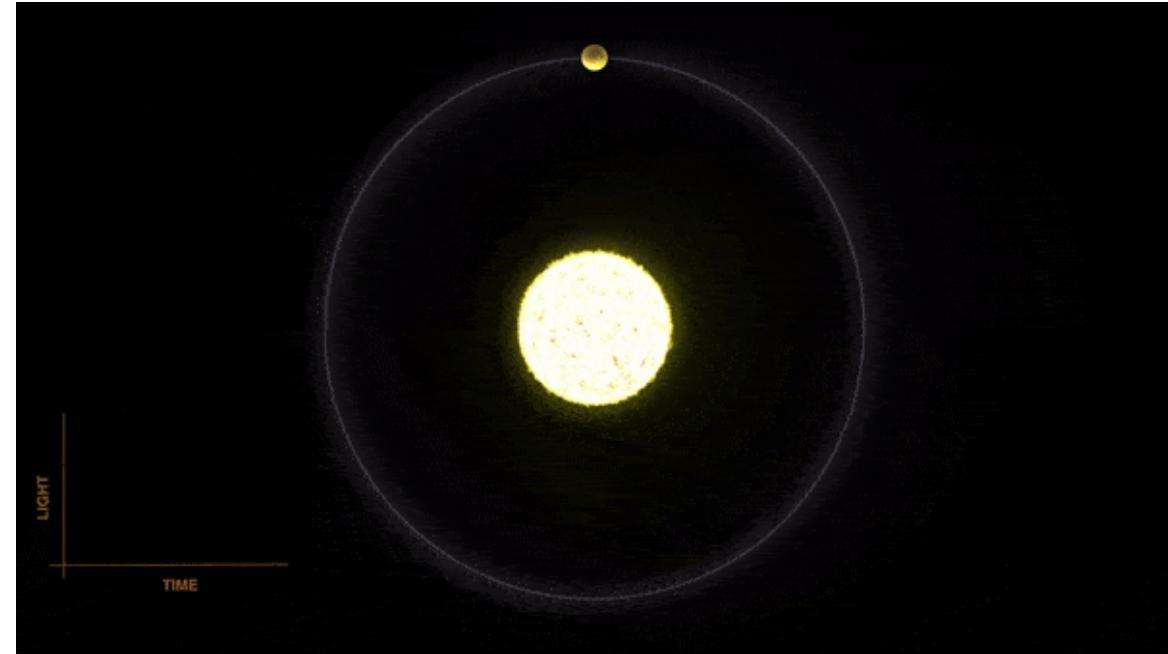
Template transits using a range of:

- periods
- depths
- durations



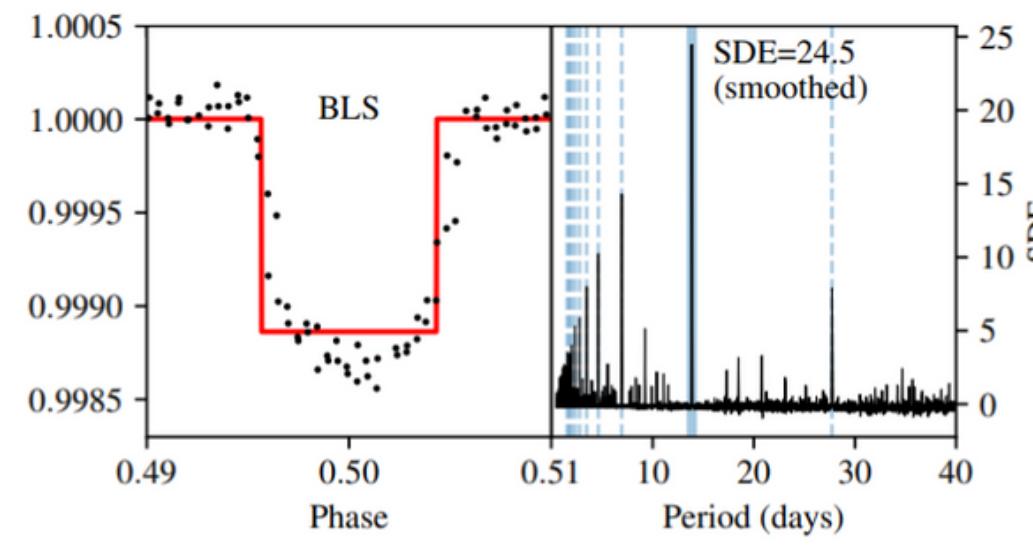
Box Least Squares
(Kovacs *et al.* 2002)

How to search for planets in photometric data?

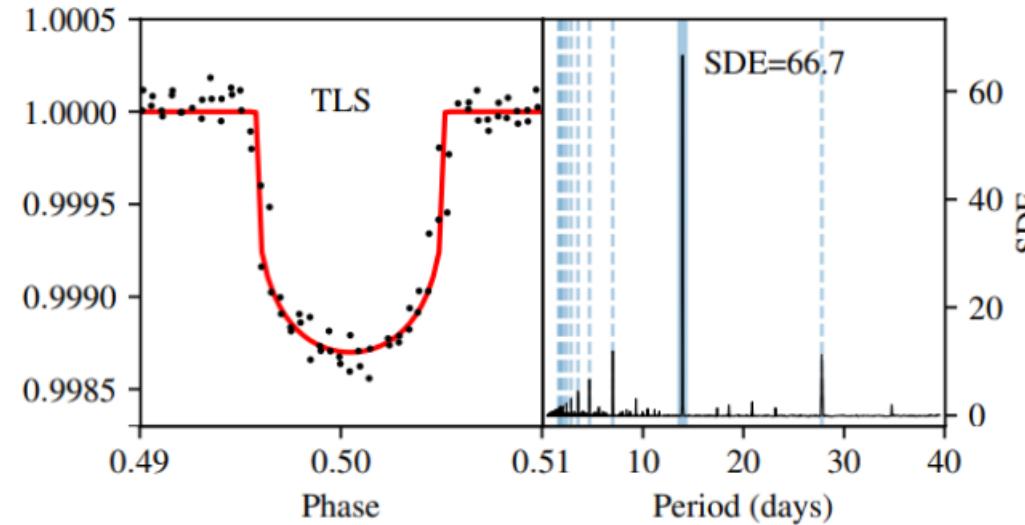


Template transits using a range of:

- periods
- depths
- durations

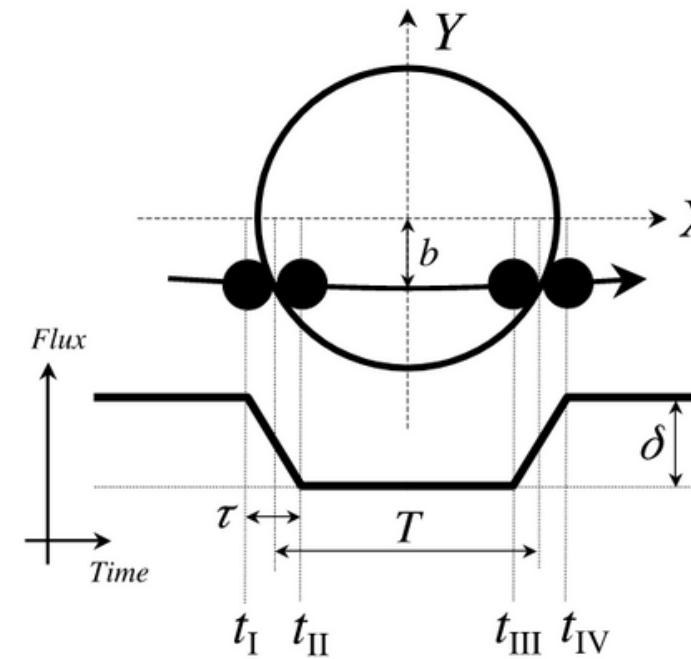
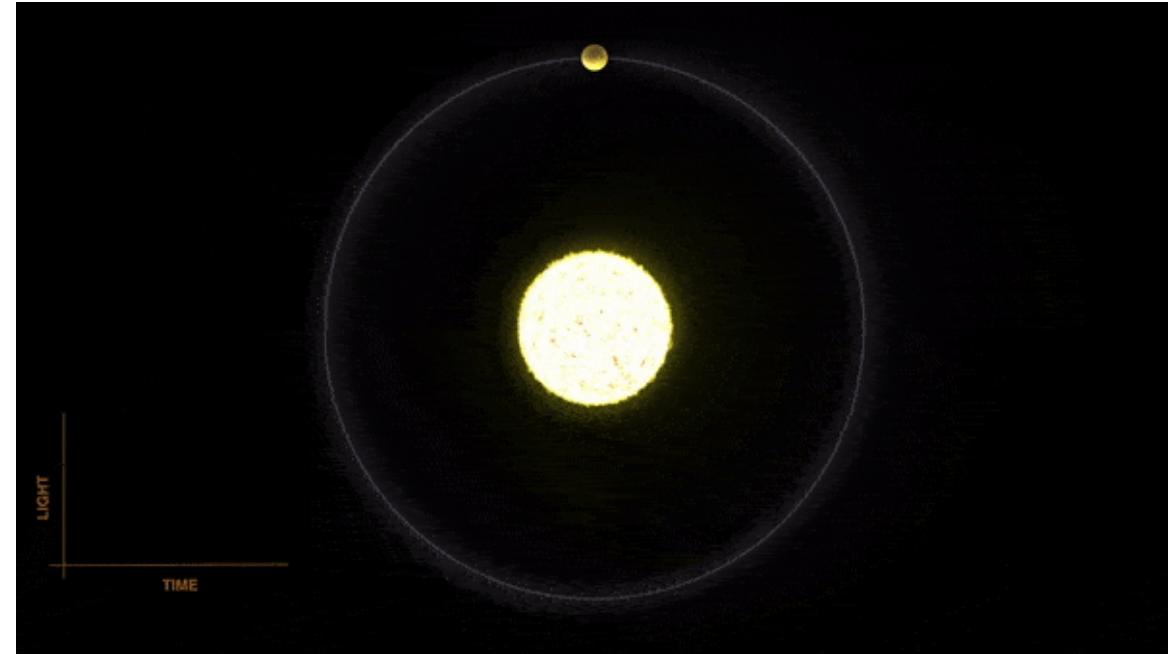


Box Least Squares
(Kovacs *et al.* 2002)



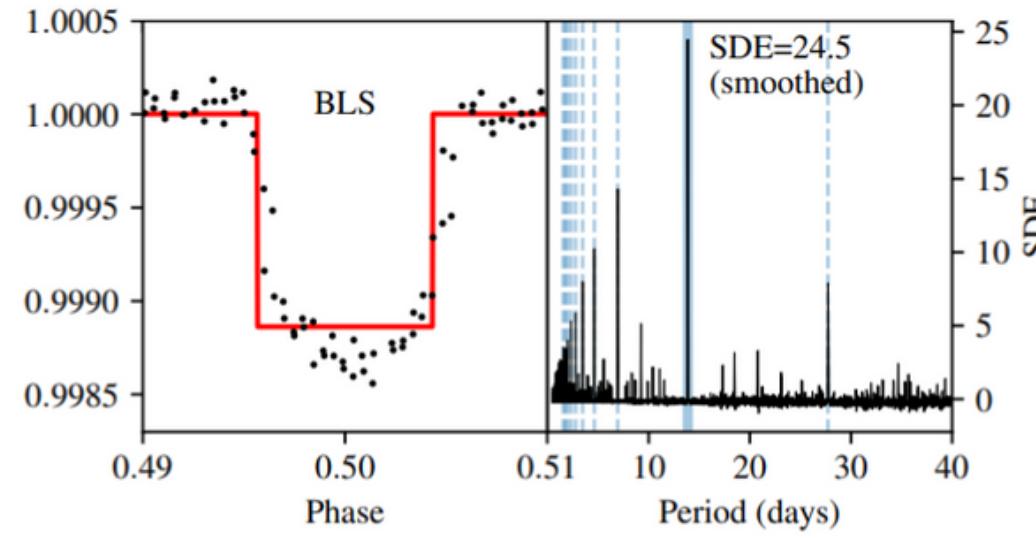
Transit Least Squares
(Hippke *et al.* 2019)

How to search for planets in photometric data?

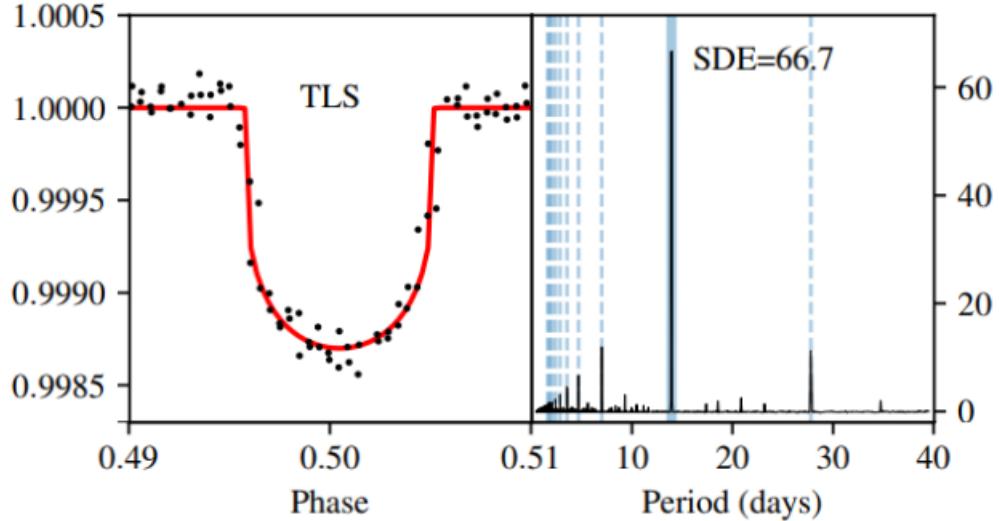


Template transits using a range of:

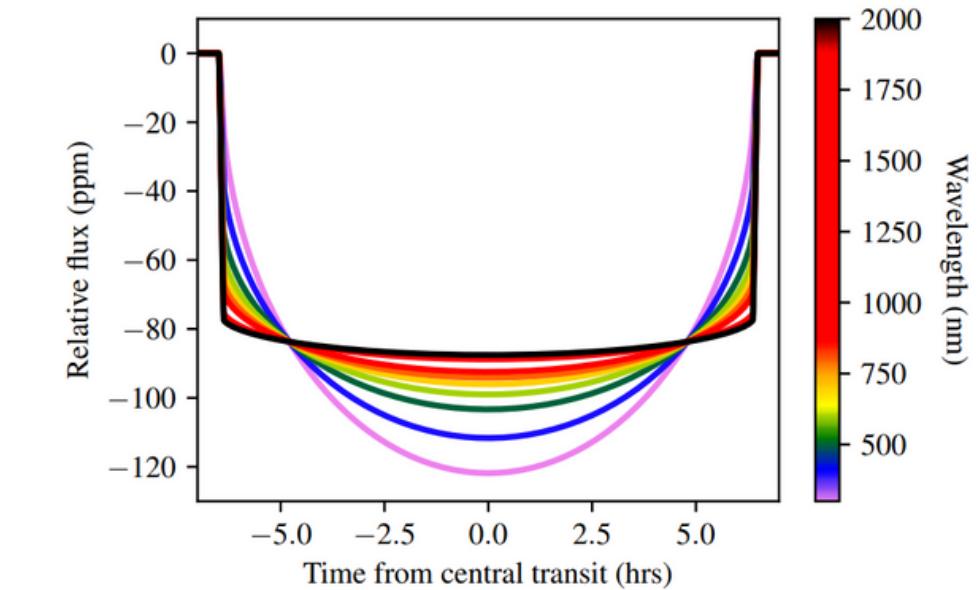
- periods
- depths
- durations



Box Least Squares
(Kovacs *et al.* 2002)



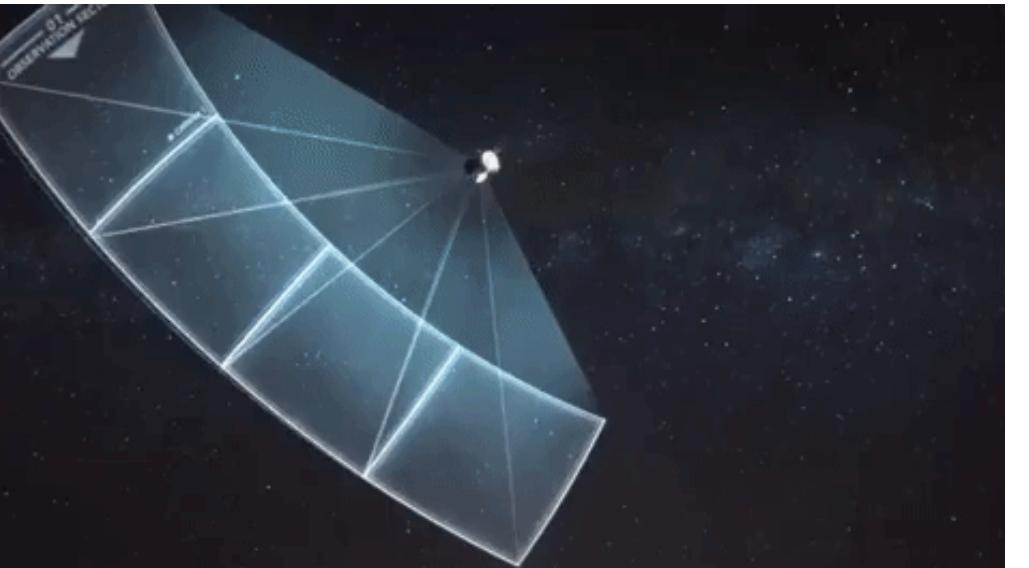
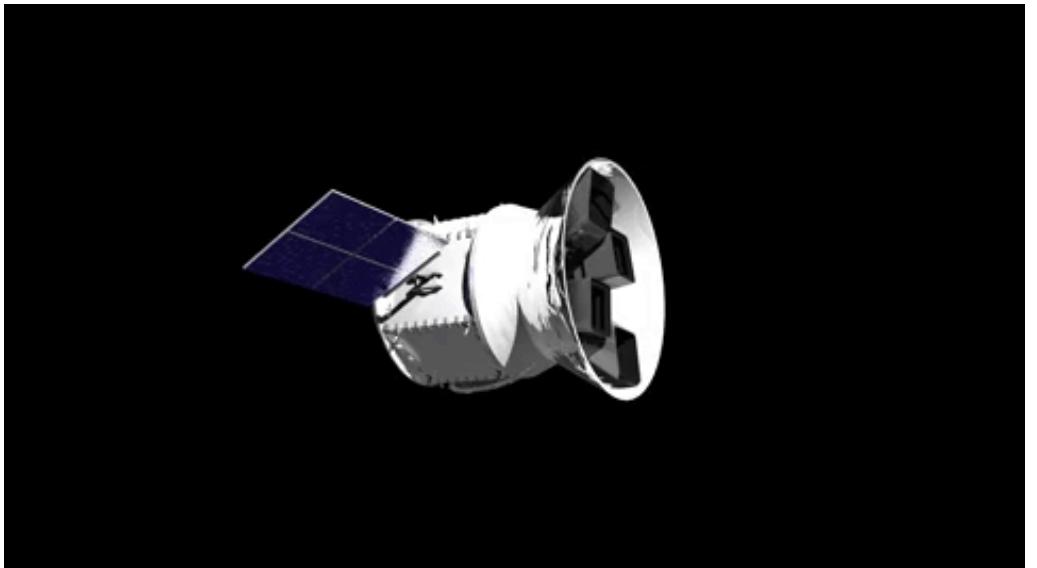
Transit Least Squares
(Hippke *et al.* 2019)



Modulate the transit shape
according to the stellar properties

TESS mission

- Primary goal: discovery of 50 L1-planets ($1\text{-}4 R_{\oplus}$, 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)



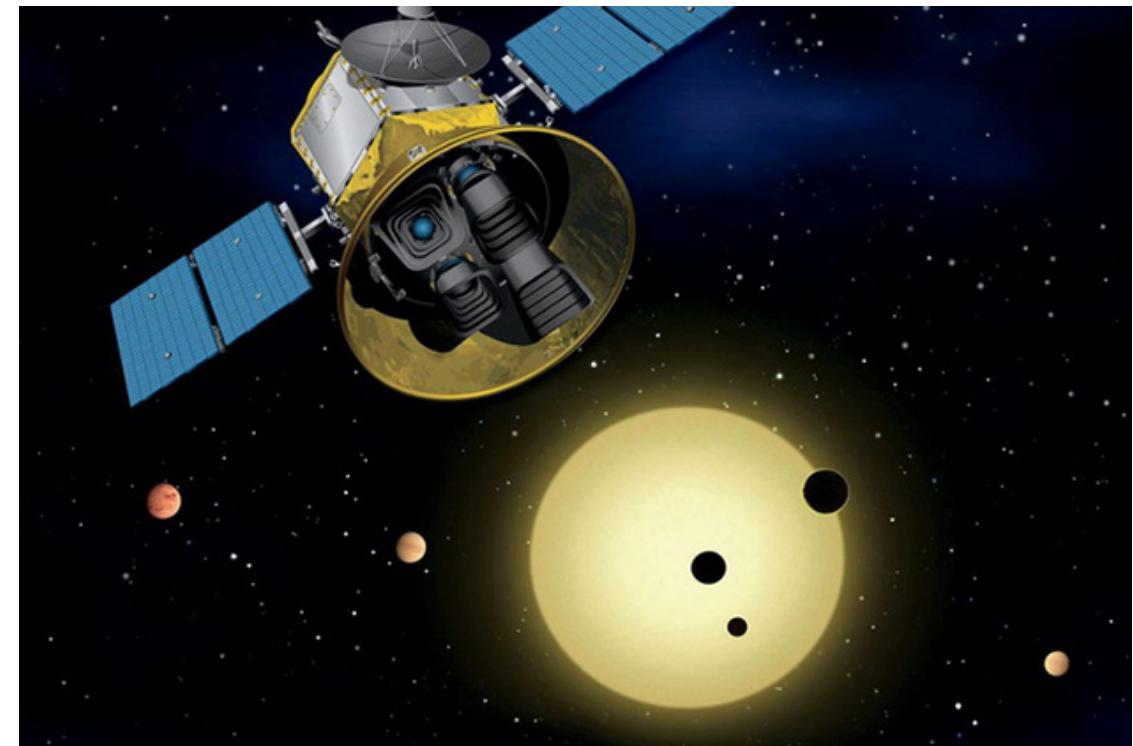
TESS mission

- Primary goal: discovery of 50 L1-planets ($1\text{-}4 R_{\oplus}$, nearby, bright stars)
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- Cadences: 20s, 120s, 600s, 1800s
- SPOC & QLP (Jenkins et al. 2016; Huang et al. 2020): TOIs

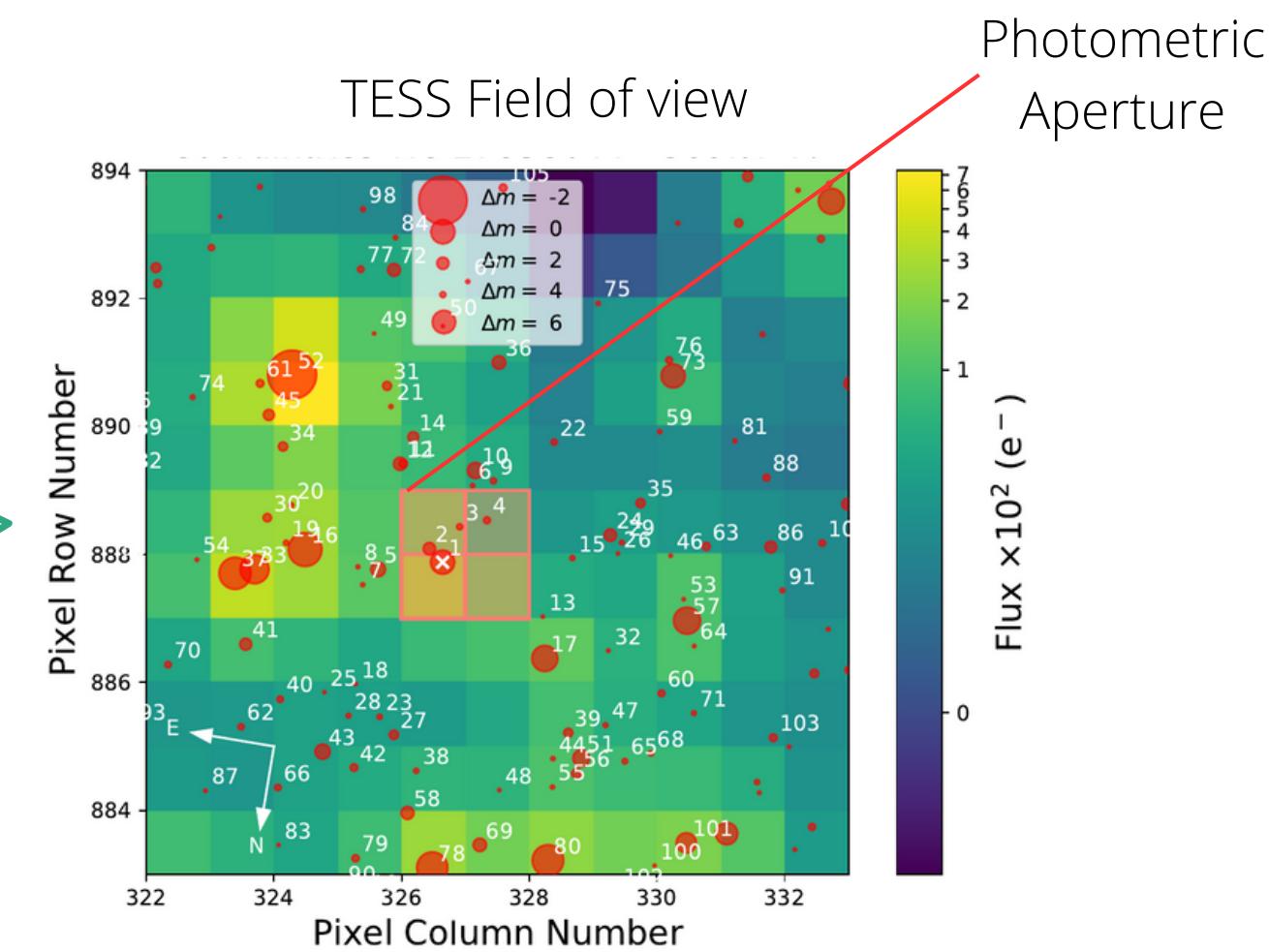
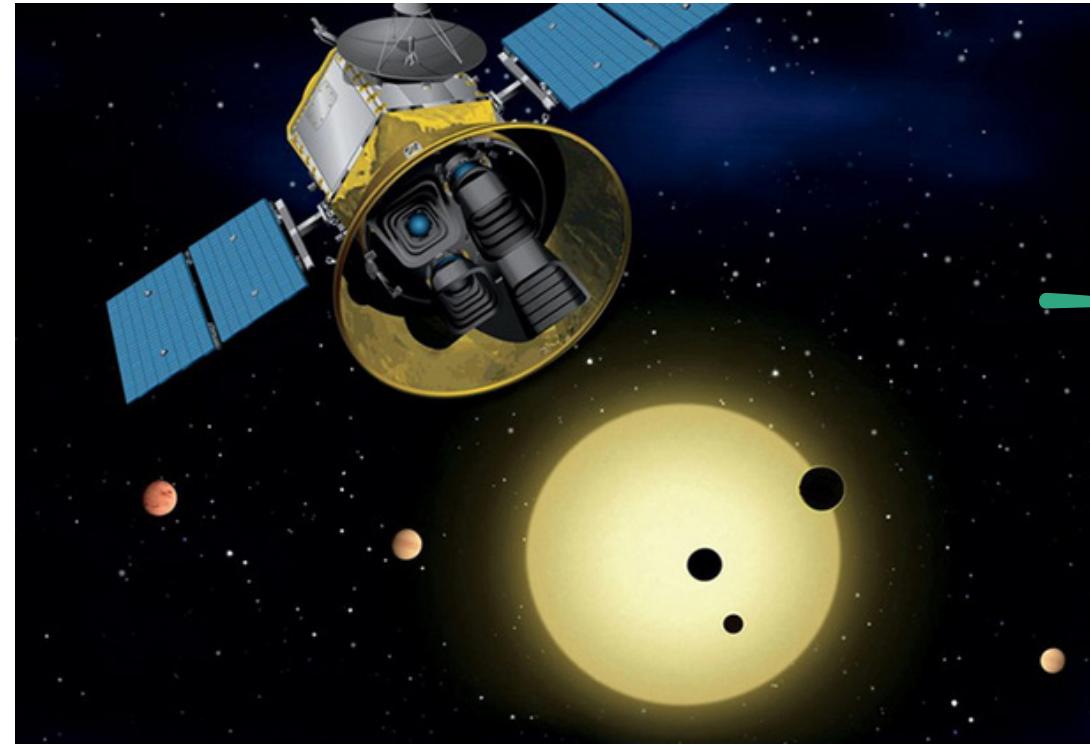
**PUBLIC
DATA!**



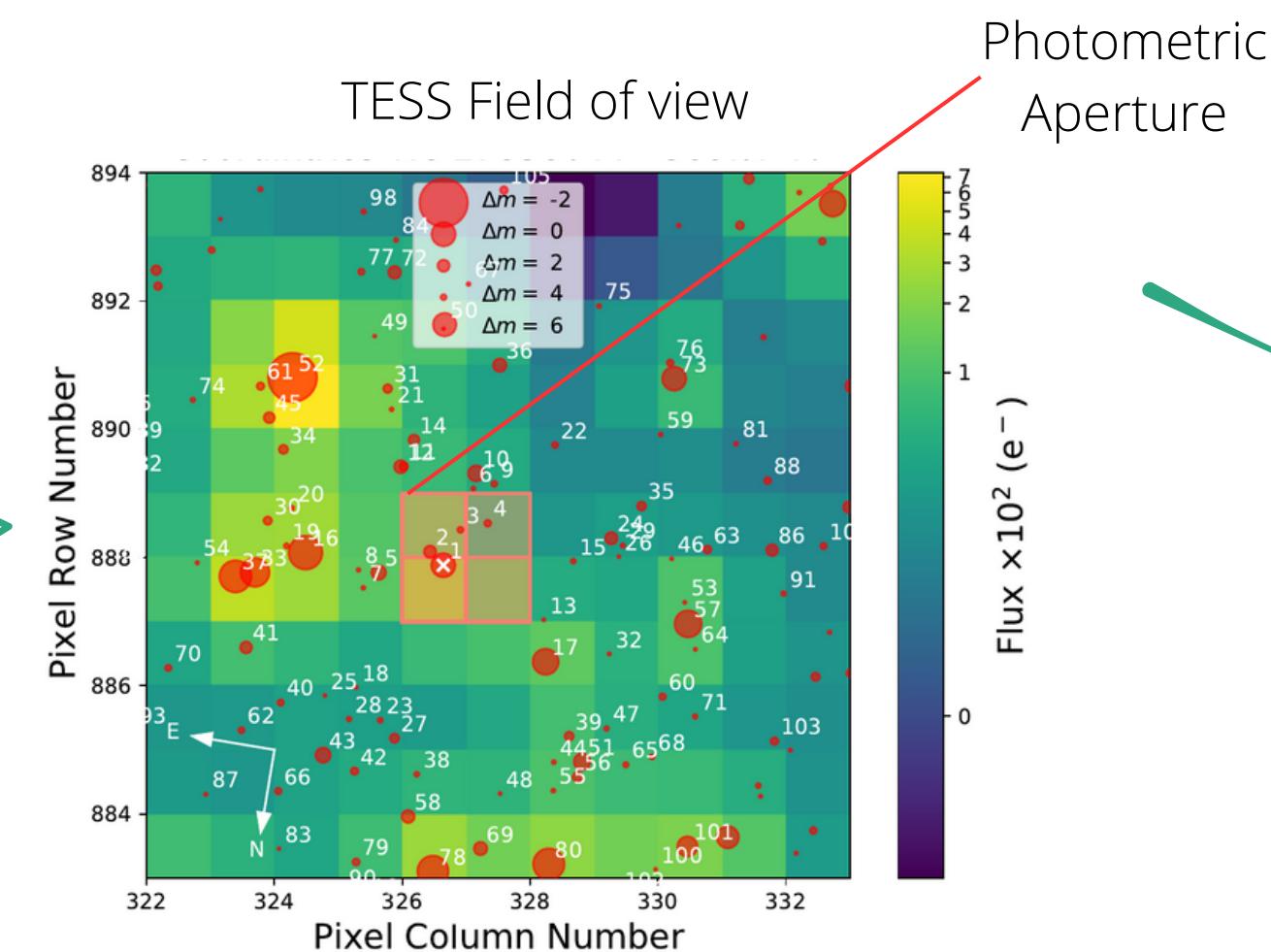
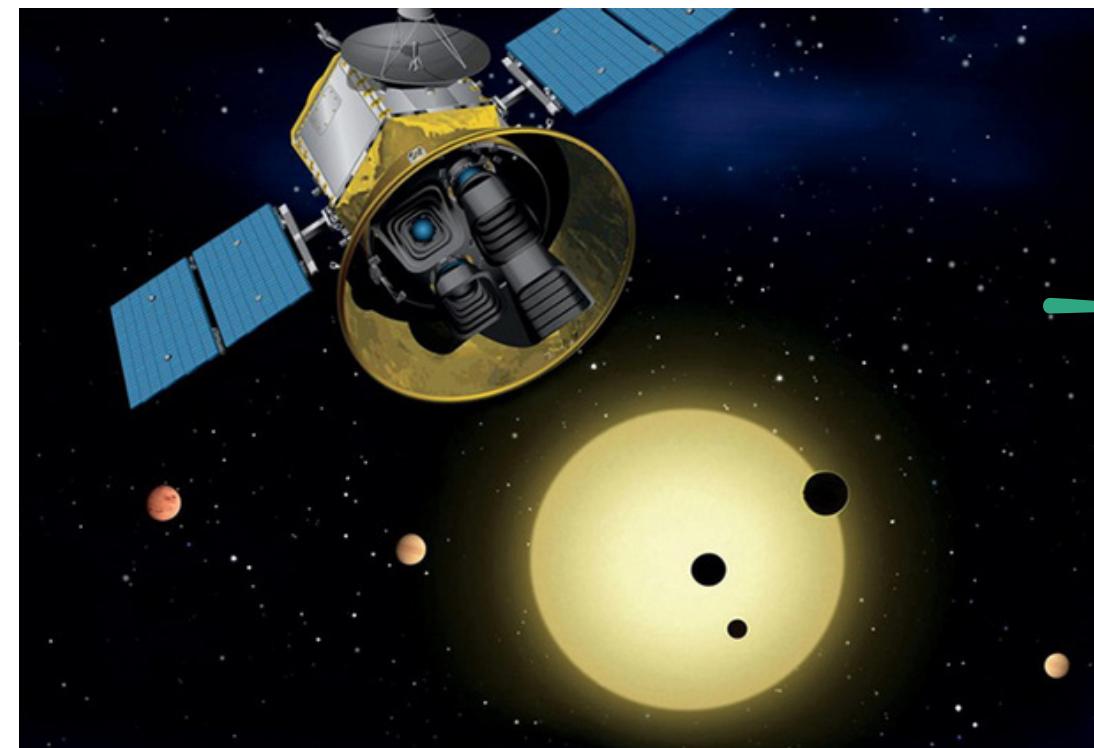
|TESS mission



TESS mission



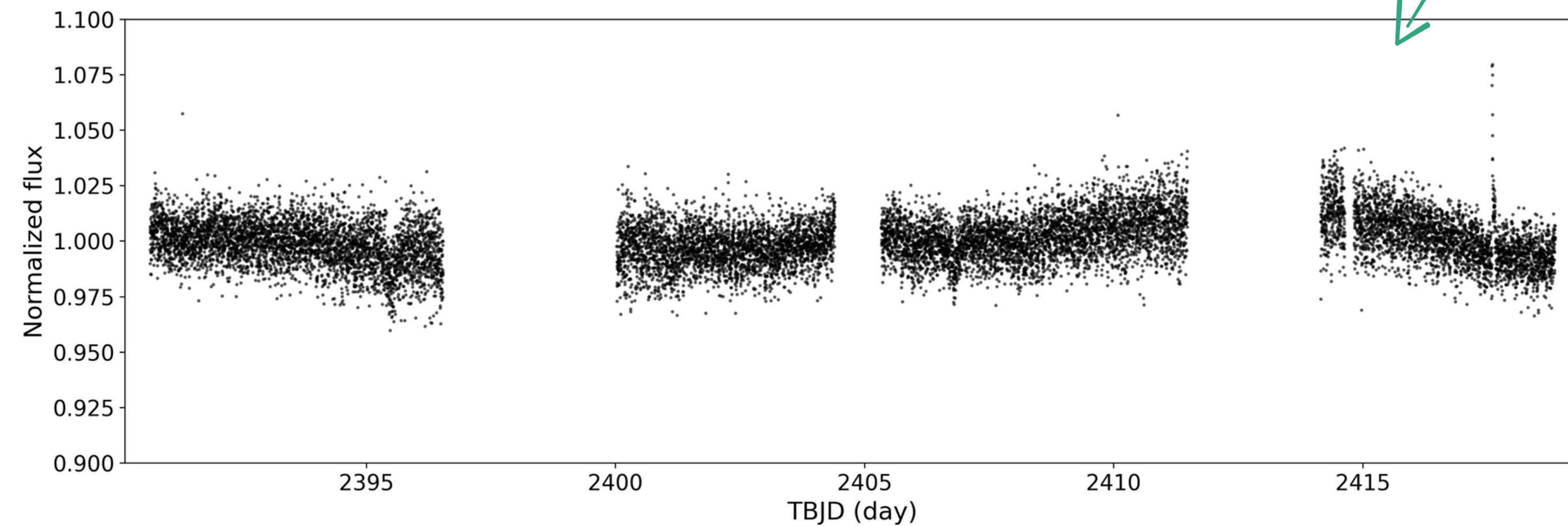
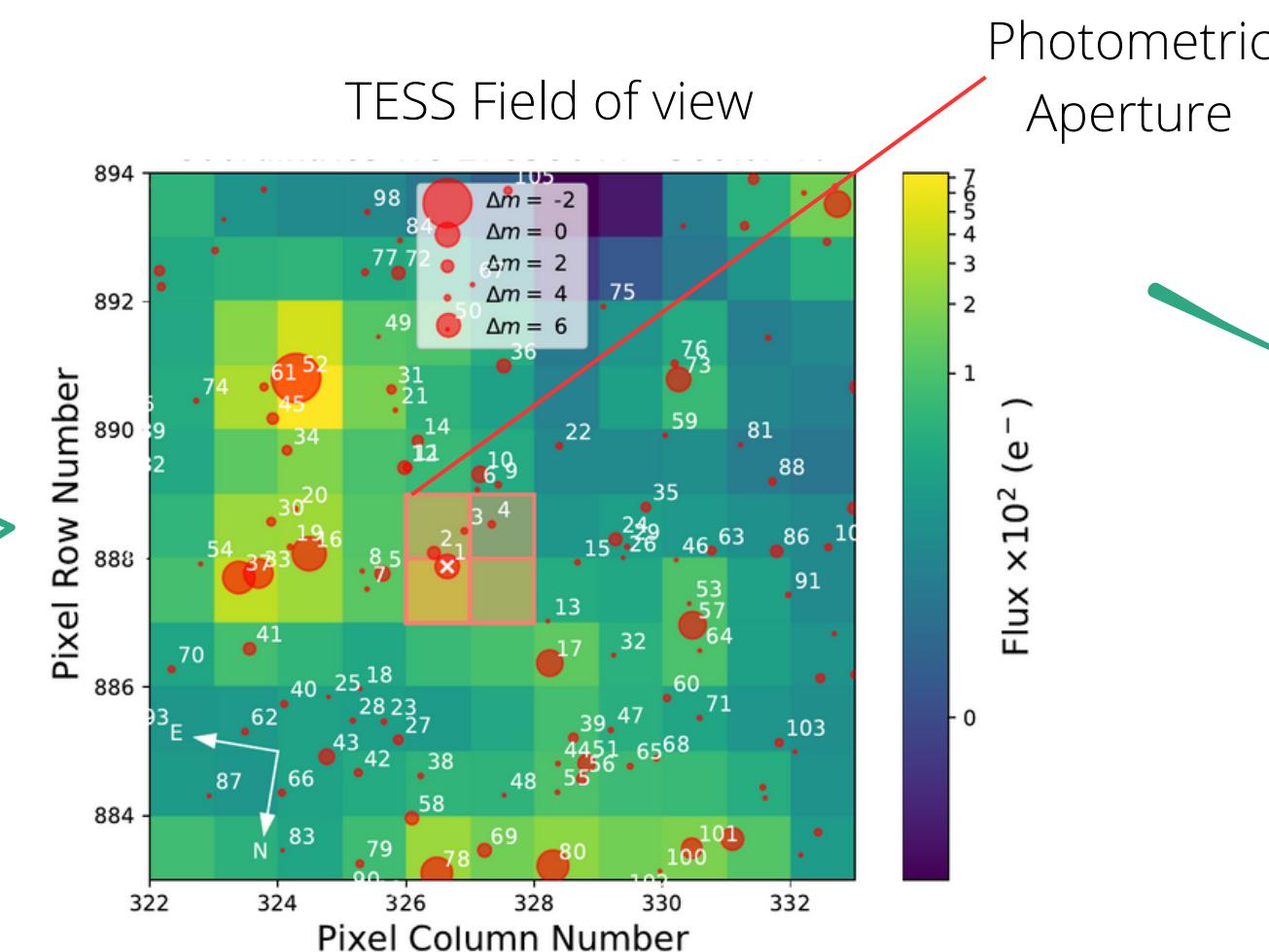
TESS mission



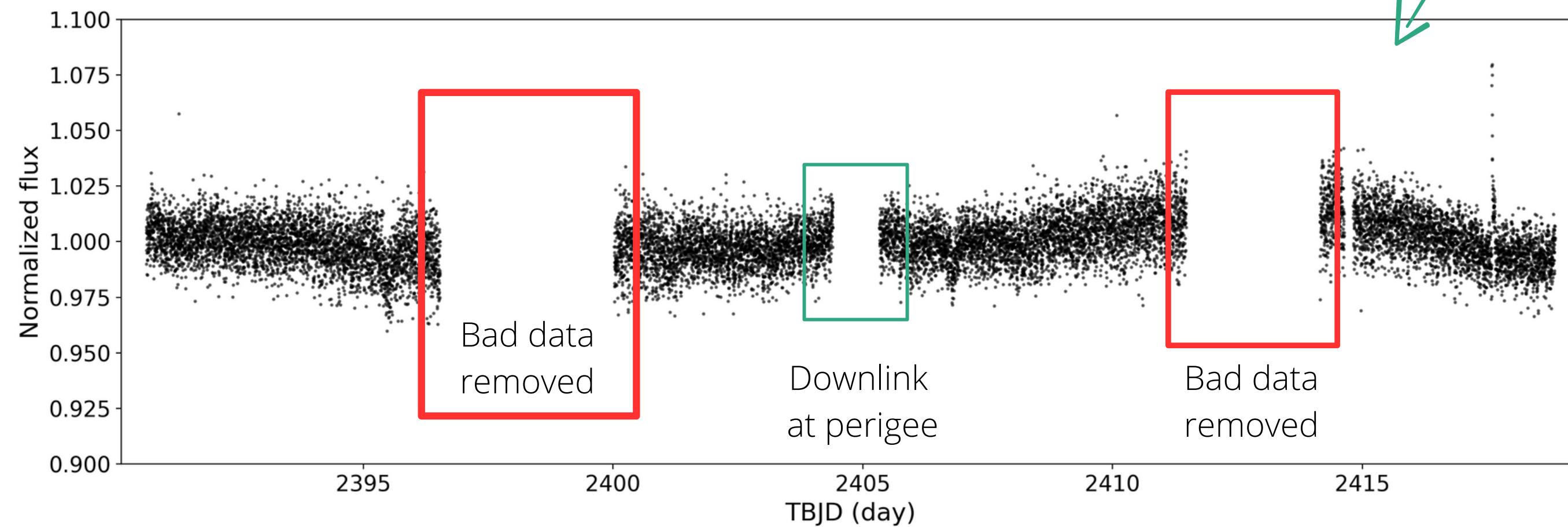
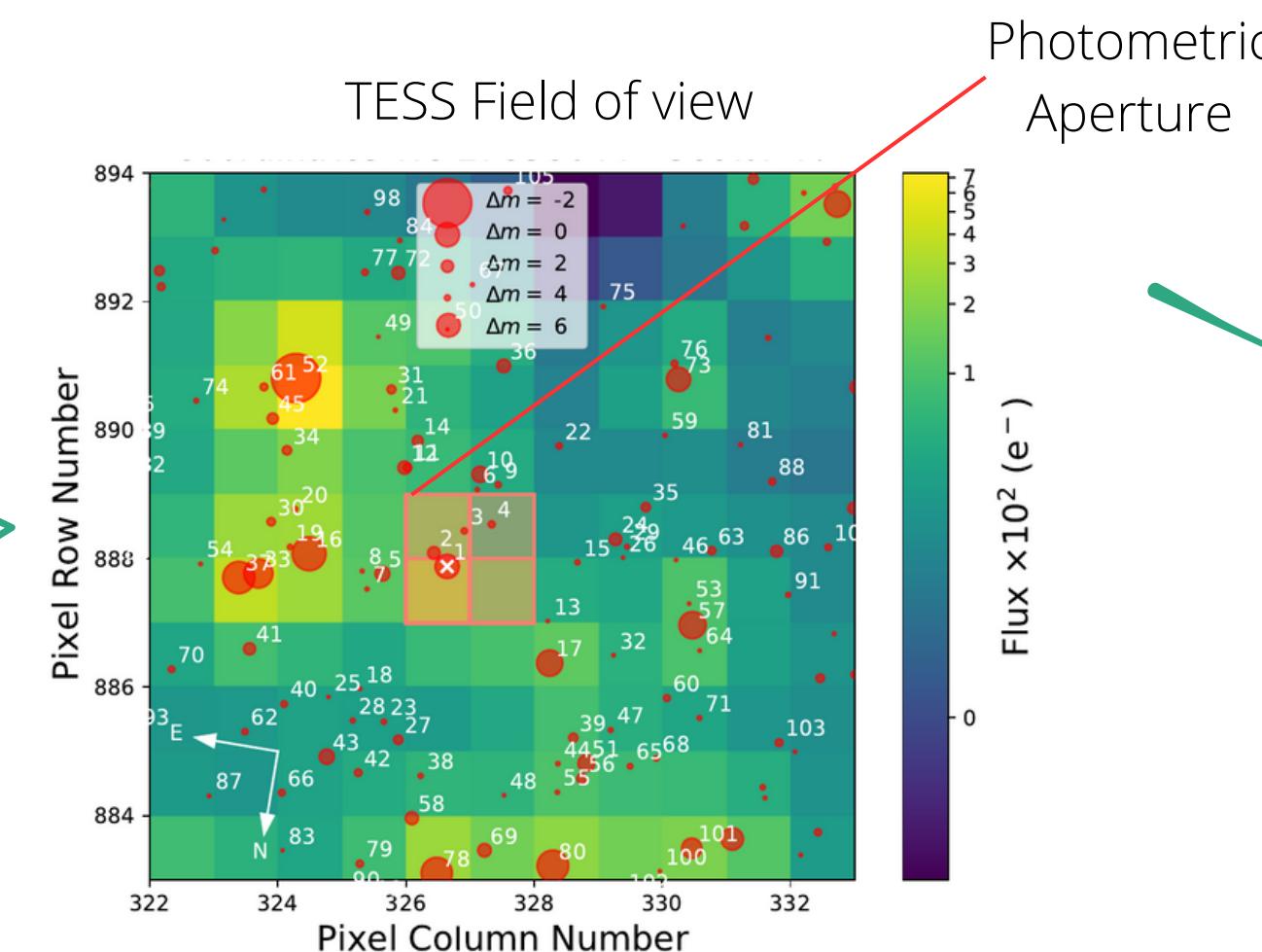
Photometric
Aperture



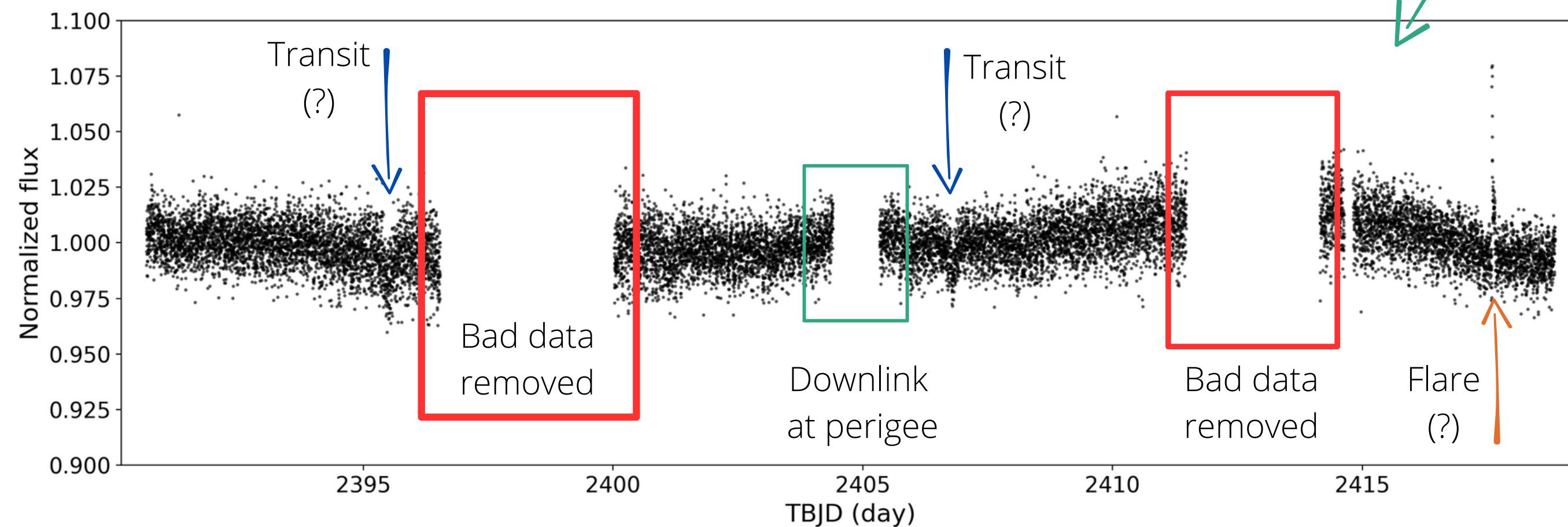
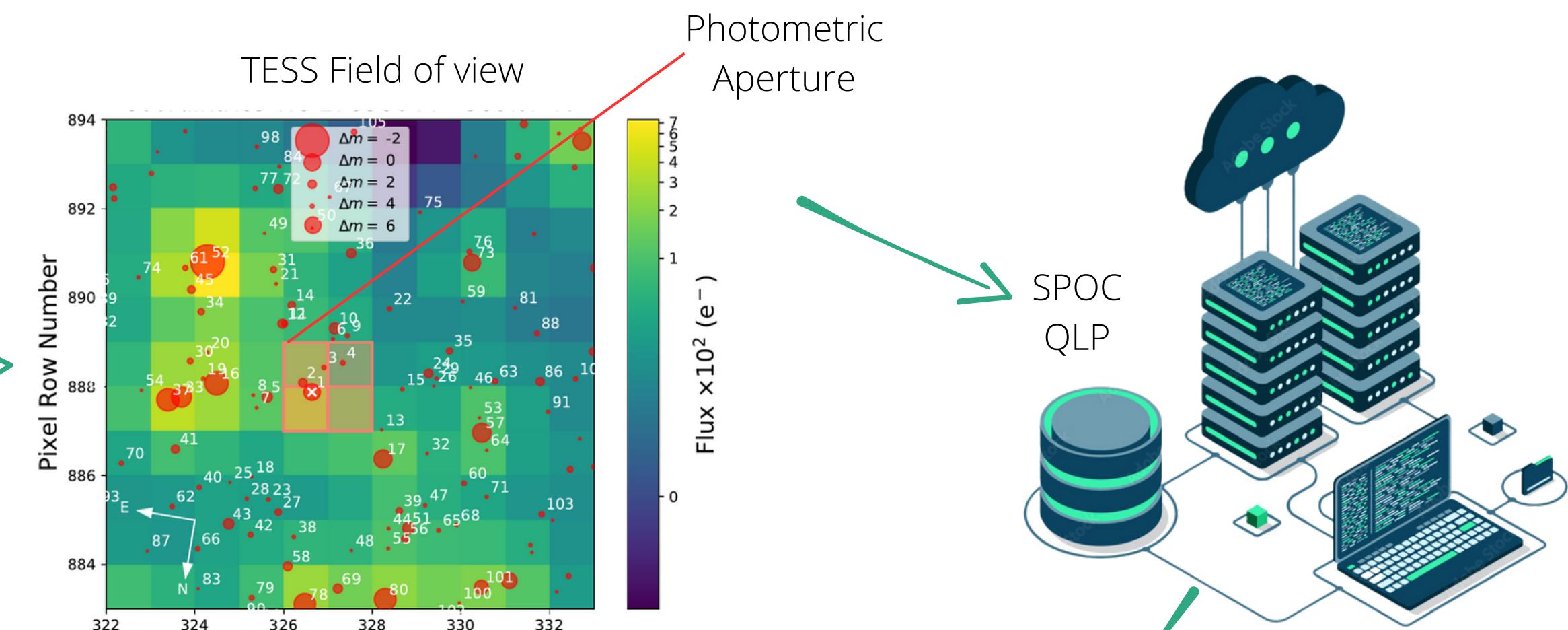
TESS mission



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



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

Where are all the TESS data products?

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

The screenshot shows the ExoFOP homepage with a blue header bar. The header includes the ExoFOP logo, a "Help" link, and a "Login" link. Below the header is a "Welcome to ExoFOP" message and a brief description of the program's purpose. The main content area features several sections: "News" (with a yellow header), "ExoFOP Professional Conduct Policy" (with a green header), and a "REQUEST AN ACCOUNT" and "RESET YOUR PASSWORD" button. Below these are seven main navigation boxes: "STARS", "PLANETS", "DATA TAGS", "OBSERVATIONS", "BULK UPLOADS", "TFOP WORKING GROUP", and "CHANGE LOG". Each box contains various links and search fields. At the bottom of the page is an "OTHER LINKS" box with links to "ExoFOP News", "TSM & ESM Documentation", "CBV Imaging of the Kepler Field", "ExoFOP Download Functions", "Tools (Python Notebooks)", "Searchmore Finding Chart", "TESS Camera 4 Image Mosaic", and "ExoFOP Directory". Logos for NASA, Caltech, Kepler, and TESS are at the very bottom.

Where are all the TESS alerts?

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

| Why SHERLOCK?

Why SHERLOCK?

- Easy access to the TESS data



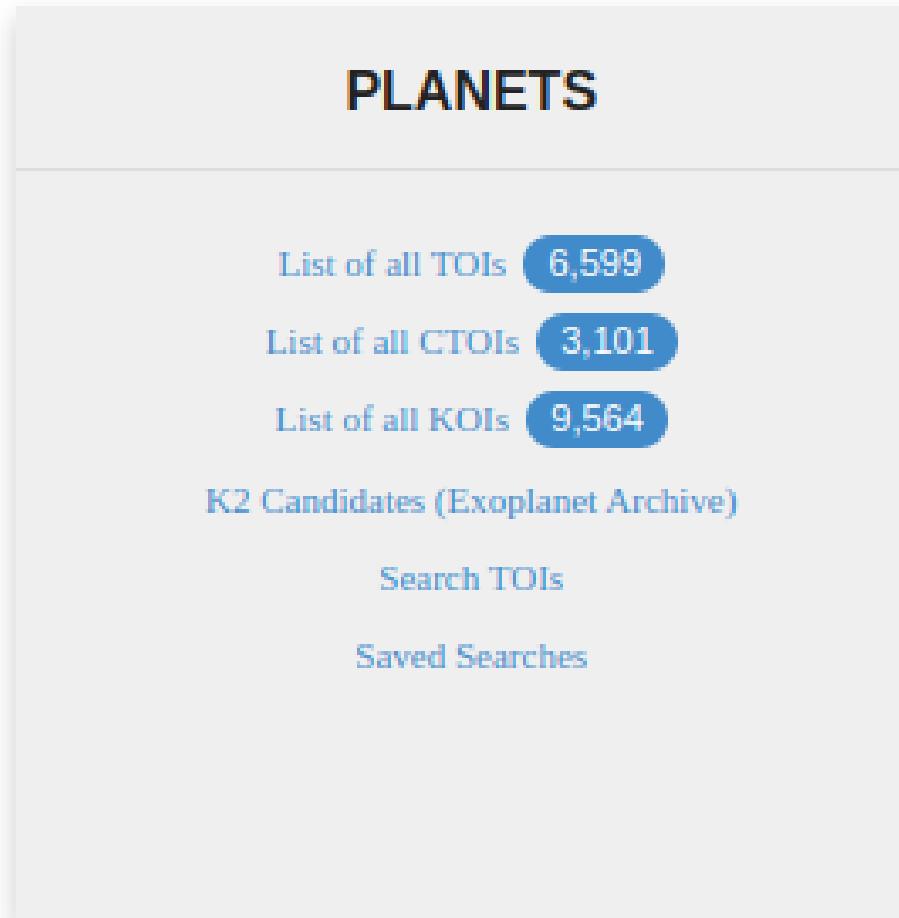
Just using the TIC-ID!



tess_lightcurves.ipynb

Why SHERLOCK?

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



TESS Objects of Interest (TOIs)

Community TESS Objects of Interest (CTOIs)

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

Why SHERLOCK?

THE ASTROPHYSICAL JOURNAL LETTERS

- 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 |

OPEN ACCESS

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

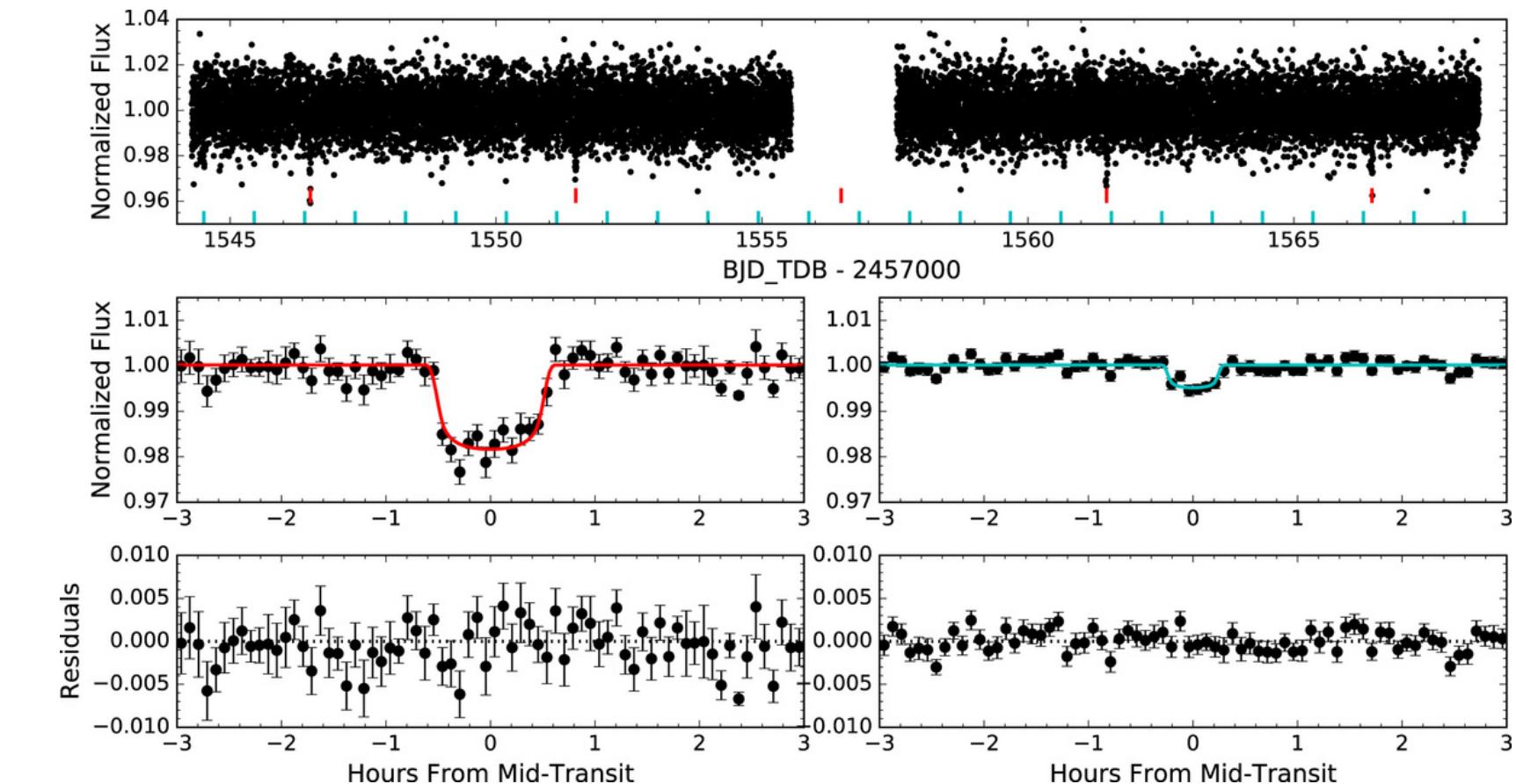
Ian J. M. Crossfield¹, William Waalkes^{33,2} , Elisabeth R. Newton³ , Norio Narita^{4,5,6,7} , Philip Muirhead⁸ , Kristo Ment⁹ , Elisabeth Matthews¹, Adam Kraus¹⁰ , Veselin Kostov¹¹ , Molly R. Kosiarek^{33,12}  + Show full author list

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

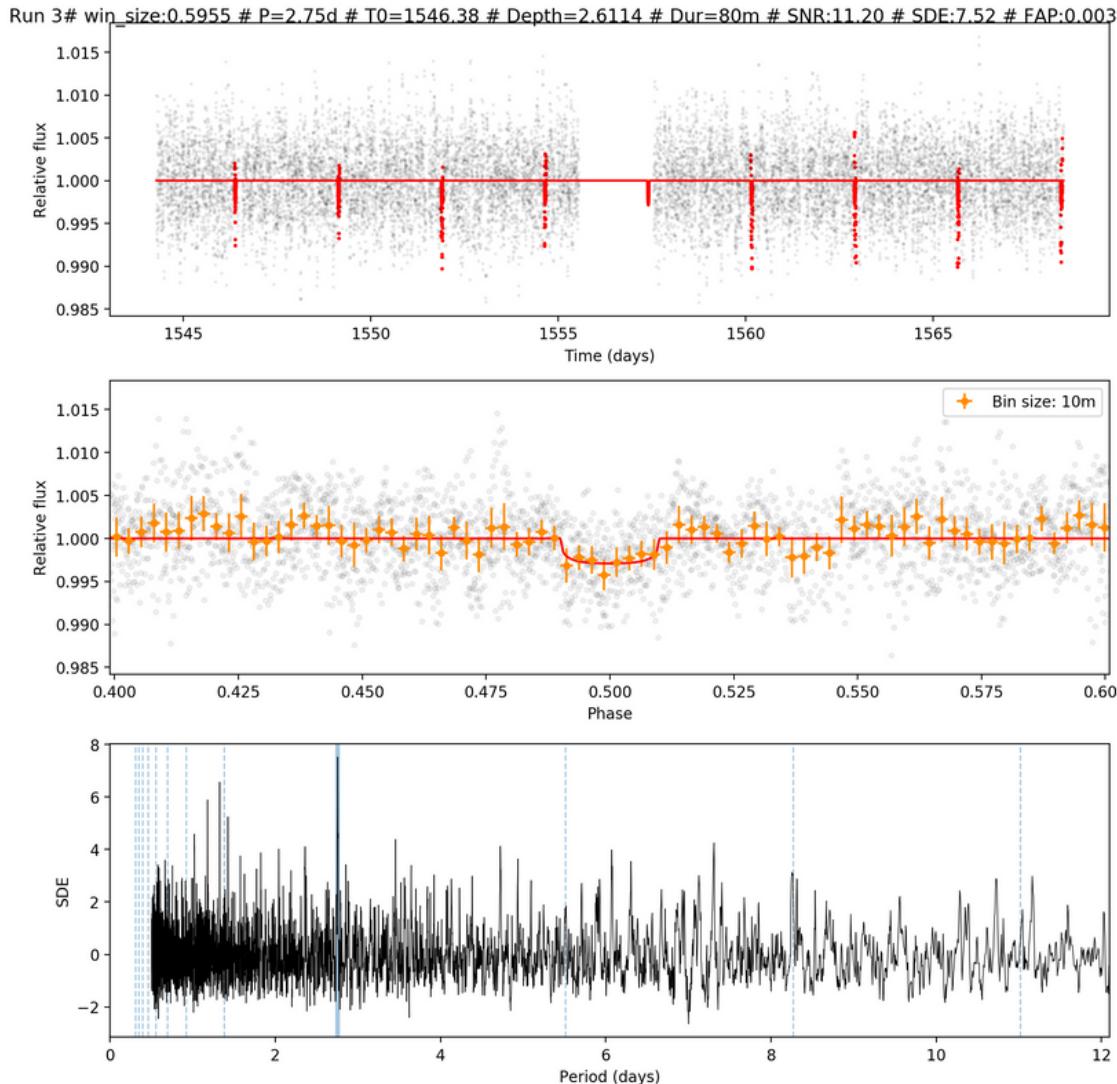
DOI [10.3847/2041-8213/ab3d30](https://doi.org/10.3847/2041-8213/ab3d30)



(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

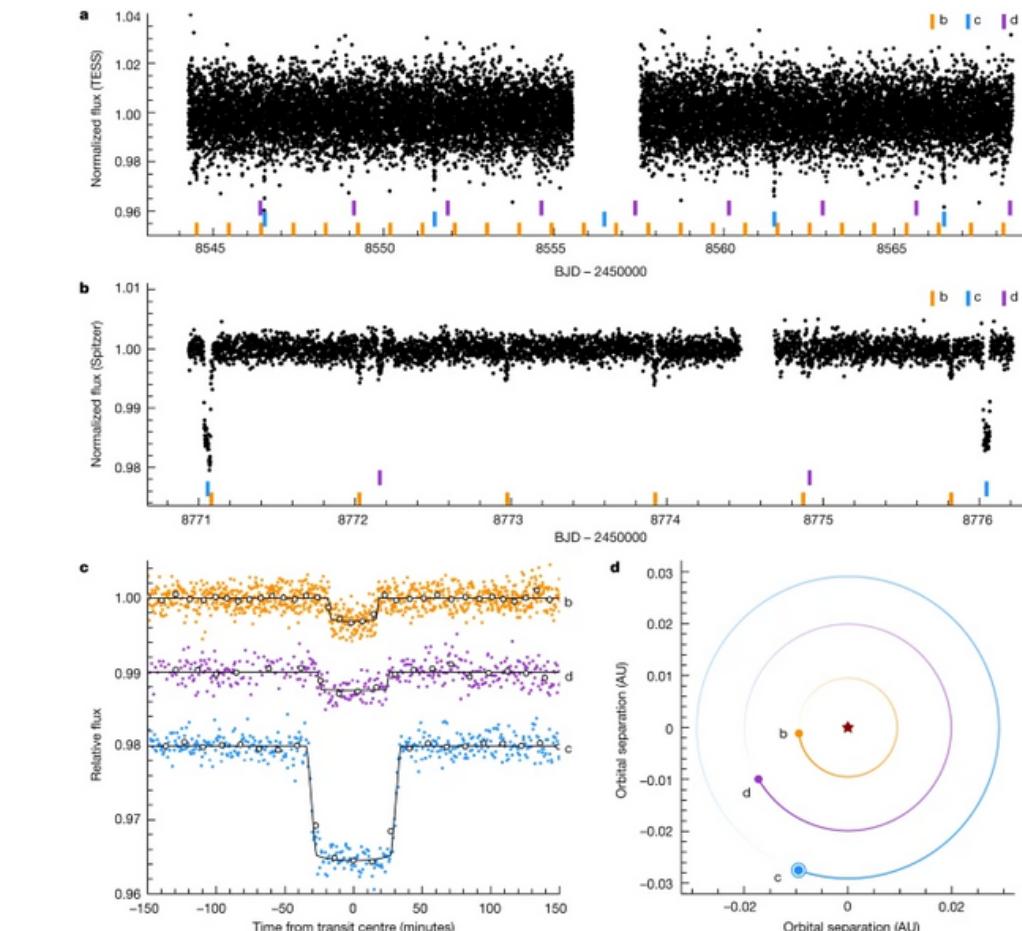
A temperate Earth-sized planet with tidal heating transiting an M6 star

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.

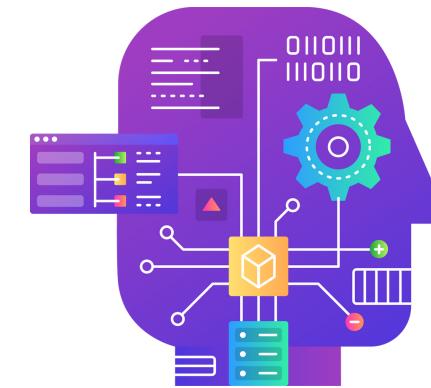


(Peterson et al. 2023)

Why SHERLOCK?

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

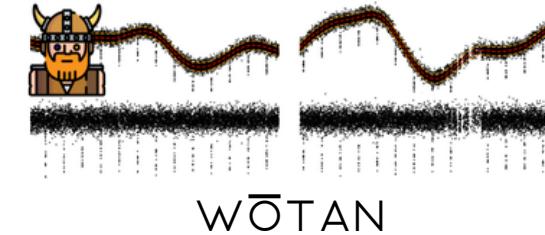
- 1 Multi-detrend approach
- 2 Savitzky-Golay filter
- 3 Transit Least Square & Box Least Square
- 4 Automatic selection
- 5 Mask & Search



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!**

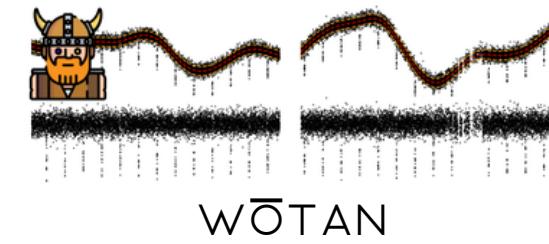
(II) Workflow and scientific cases

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

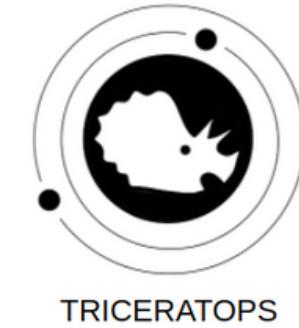


The six SHERLOCK modules

Lightkurve



Transit Least
Squares

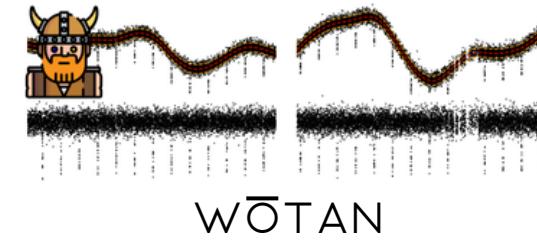


A
ALLESFITTER



The six SHERLOCK modules

Lightkurve



WOTAN

(1)

Prepare the
data

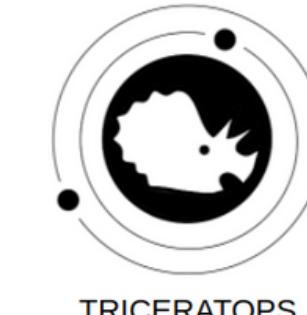
Transit Least
Squares

(2)

Search for
candidates



WATSON



TRICERATOPS

(3)

Vetting

A
ALLESFITTER

(5)

Fitting

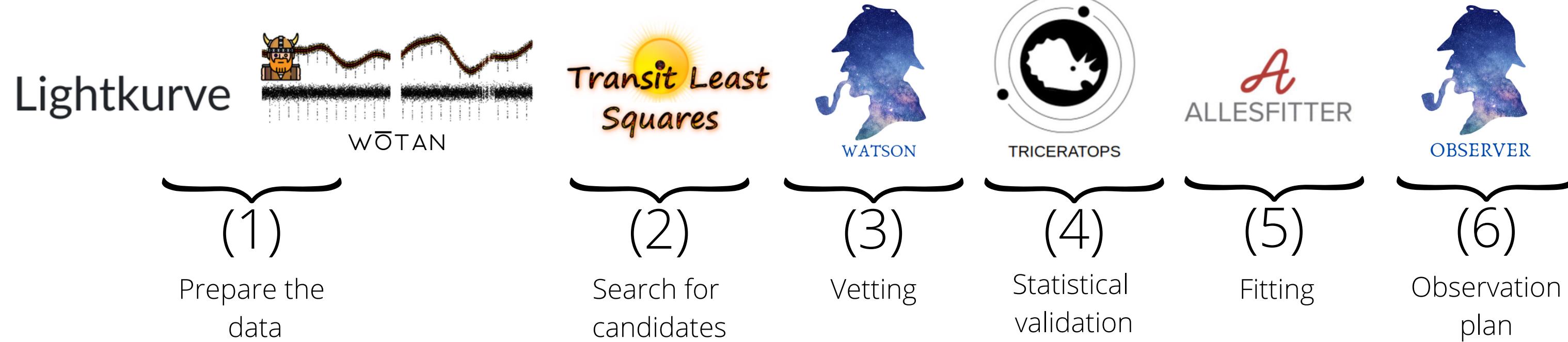


OBSERVER

(6)

Observation
plan

The six SHERLOCK modules

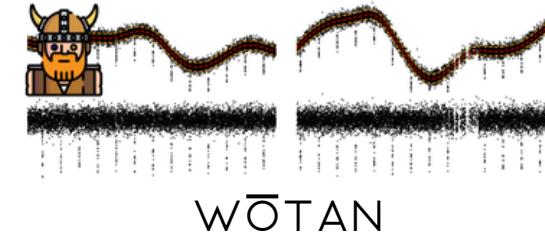


6 command lines

- ```
(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

Lightkurve



(1)

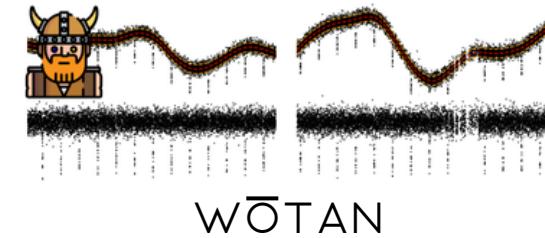
Prepare the  
data



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

# The six SHERLOCK modules

Lightkurve



(1)

Prepare the  
data



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

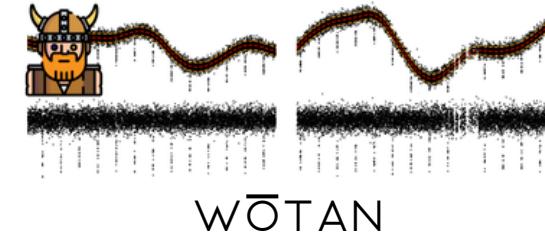
```
1 TARGETS:
2 TIC xxxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2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



TICxxxxxxxx\_explore

# The six SHERLOCK modules

Lightkurve



(1)

Prepare the  
data



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

A screenshot of a code editor window titled "explore.yaml". The file contains the following configuration:

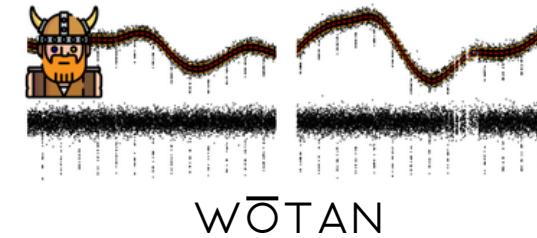
```
1 TARGETS:
2 TIC xxxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 10
12 DETREND_CORES: 10
13 CPU_CORES: 45
14 MAX_RUNS: 2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



- 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

Lightkurve



(1)

Prepare the  
data



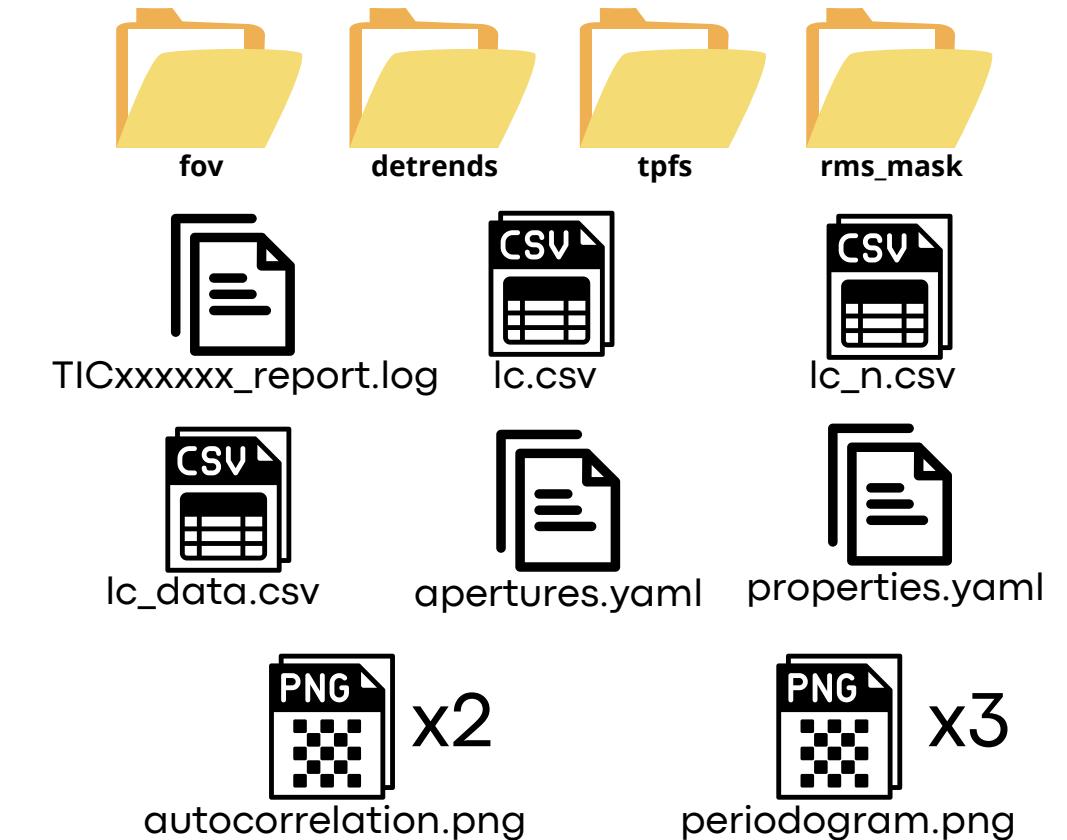
```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

```
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
```

TICxxxxxxxx\_explore

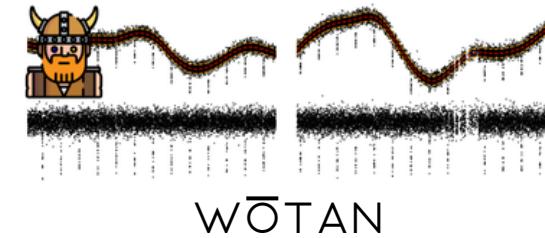


{



# The six SHERLOCK modules

Lightkurve



(1)

Prepare the  
data



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



TICxxxxxx\_report.log



detrends

```
Abrir ▾ F+ explore.yaml ~/Escritorio/EXOPLANETAS... Guardar ⌂ - ⌂ X
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
```

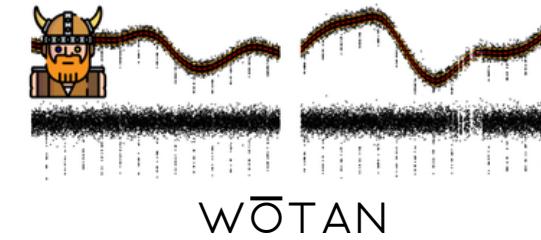
- **MODE: GLOBAL / SECTOR / BOTH**
- **EXPTIME: 20 / 120 / 600 / 1800**
- **PERIOD\_MIN: 0.3**
- **PERIOD\_MAX: 13**

```
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
```

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

# The six SHERLOCK modules

Lightkurve



(1)

Prepare the  
data

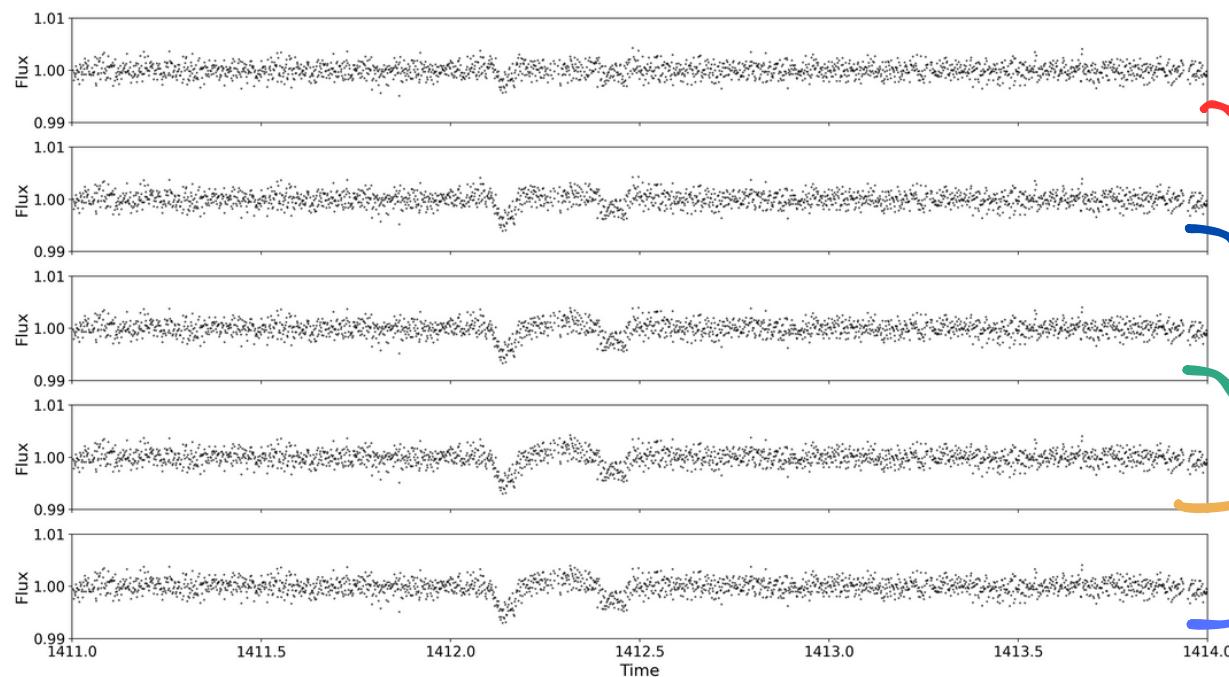


```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

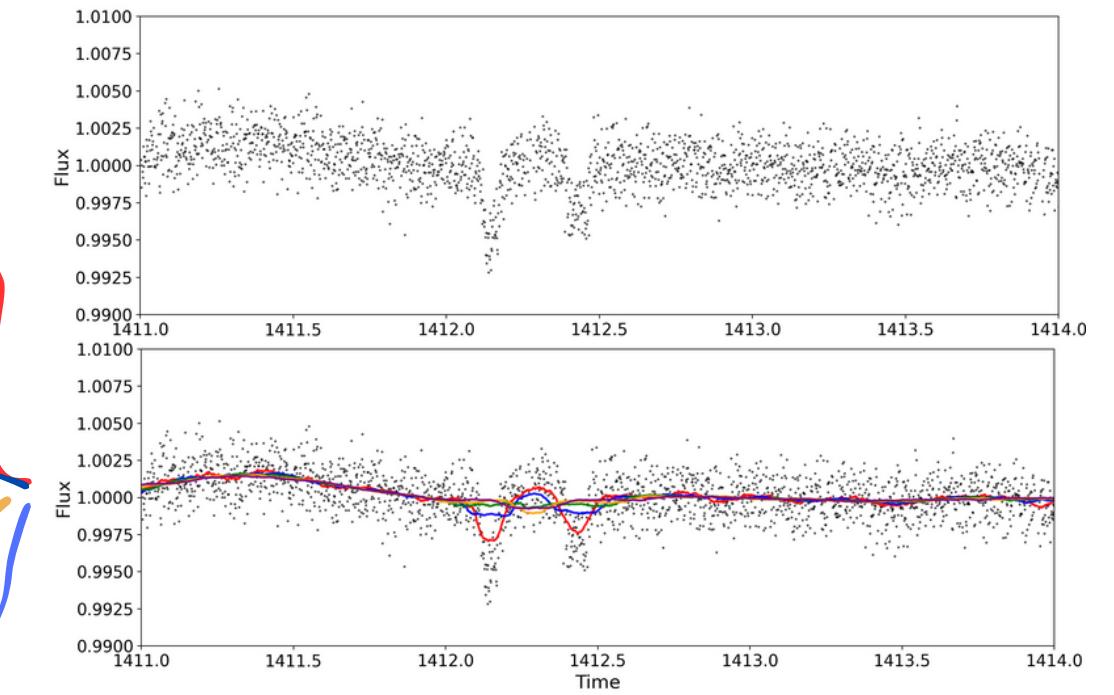


```
Abrir ▾ F+ explore.yaml ~/Escritorio/EXOPLANETAS... Guardar ⌂ - ⌂ X
1 TARGETS:
2 TIC xxxxxxxx:
3 MODE: GLOBAL
4 AUTO_DETREND_ENABLED: True
5 INITIAL_HIGH_RMS_MASK: True
6 INITIAL_SMOOTH_ENABLED: True
7 INITIAL_HIGH_RMS_THRESHOLD: 2
8 EXPTIME: 120
9 DETREND_L_MIN: 0.2
10 DETREND_L_MAX: 1.2
11 DETRENDS_NUMBER: 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
```

- DETREND\_L\_MIN: >0.1
- DETREND\_L\_MAX: <1.3
- DETRENDS\_NUMBER: 5-10

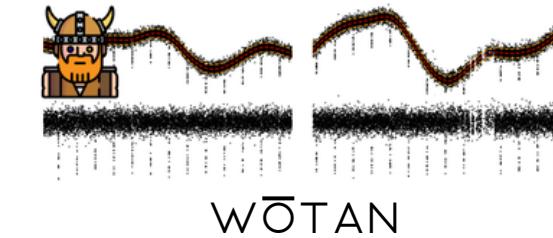


• How does the photometry look like?



# The six SHERLOCK modules

Lightkurve



(1)

Prepare the  
data



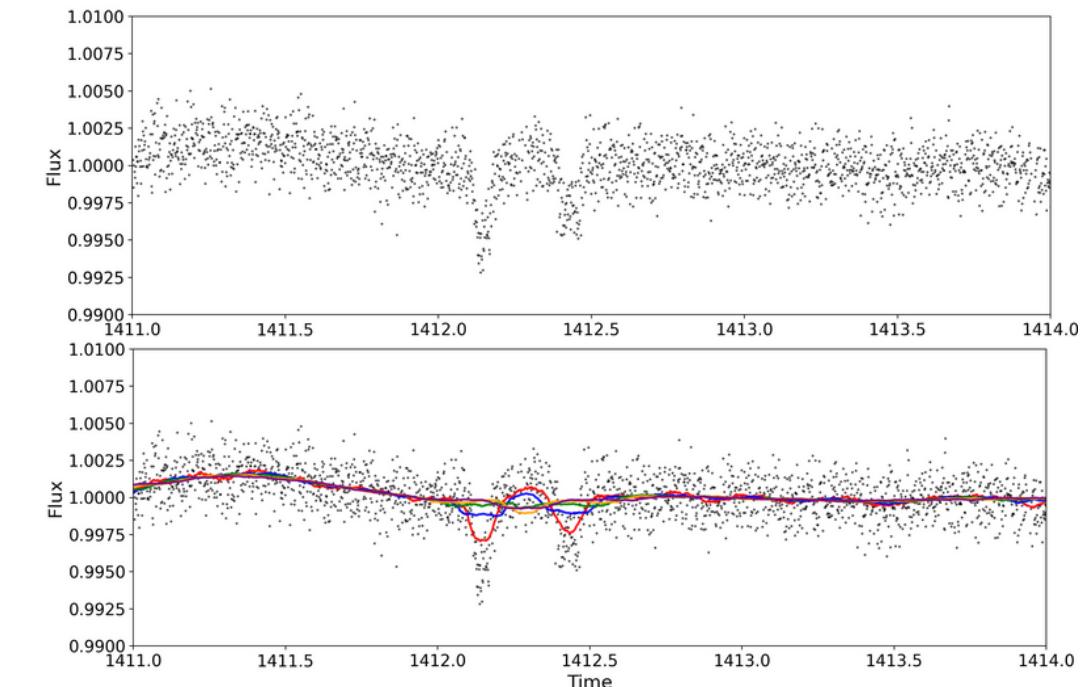
```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

```
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
```

- DETREND\_L\_MIN: >0.1
- DETREND\_L\_MAX: <1.3
- DETRENDS\_NUMBER: 5-10

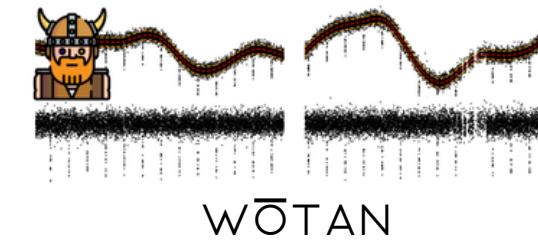


- How does the photometry look like?



# The six SHERLOCK modules

Lightkurve



(1)

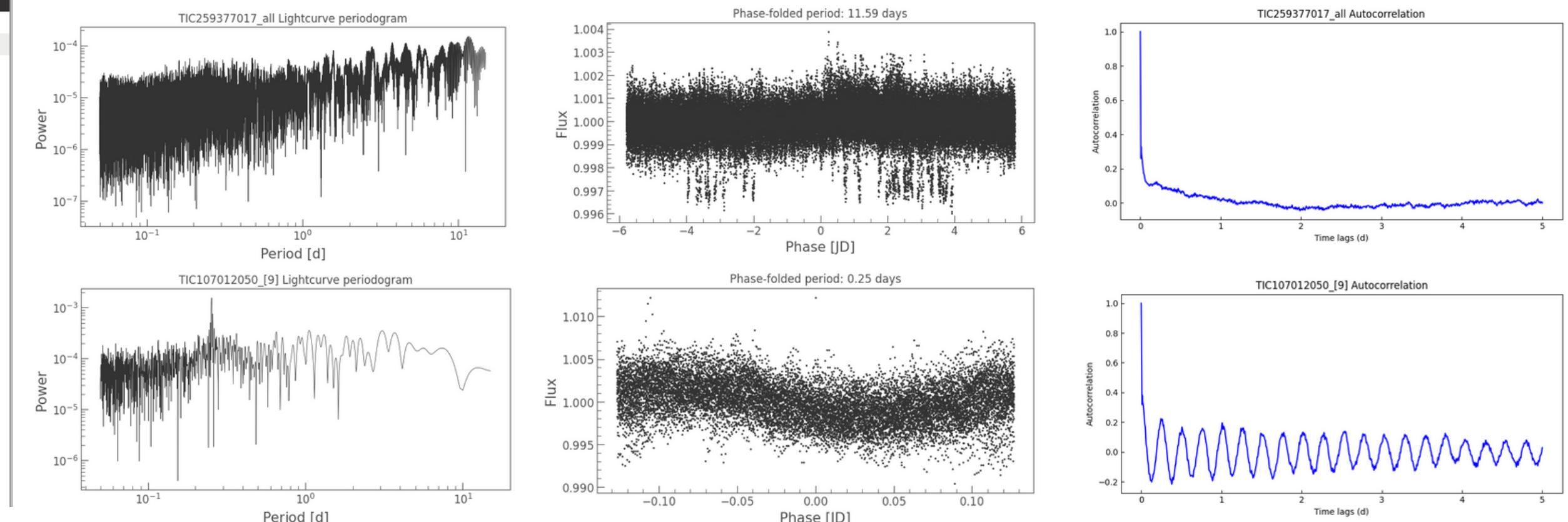
Prepare the  
data



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

- AUTO\_DETREND\_ENABLE: TRUE / FALSE

```
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
```



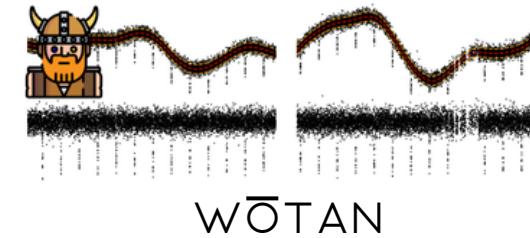
- Is it a fast rotator?

PNG x2  
autocorrelation.png

PNG x3  
periodogram.png

# The six SHERLOCK modules

Lightkurve



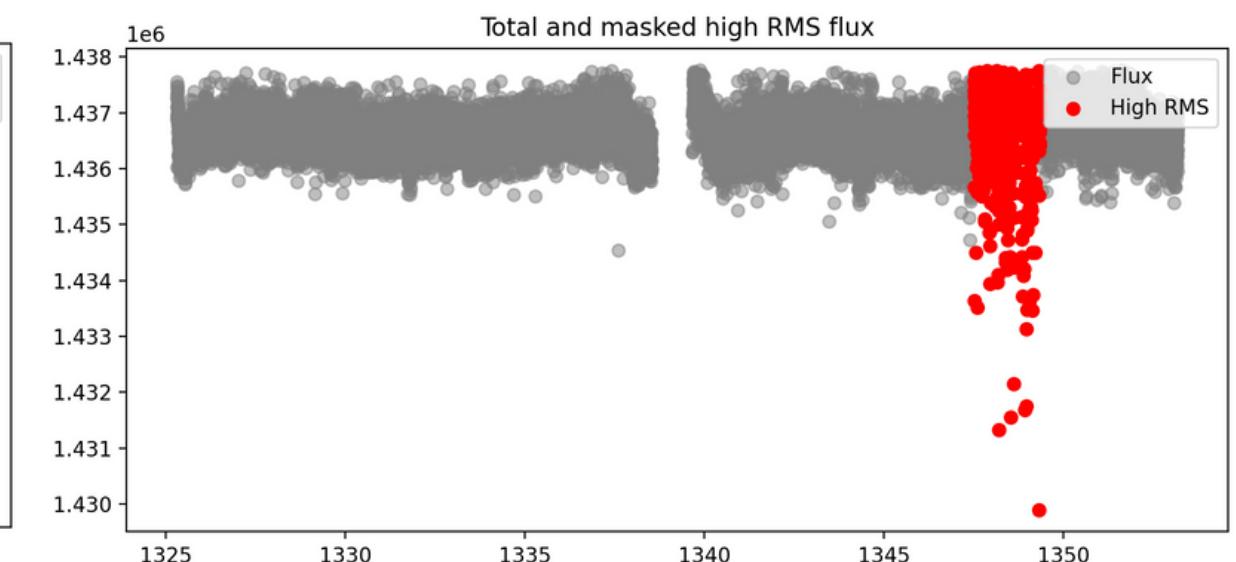
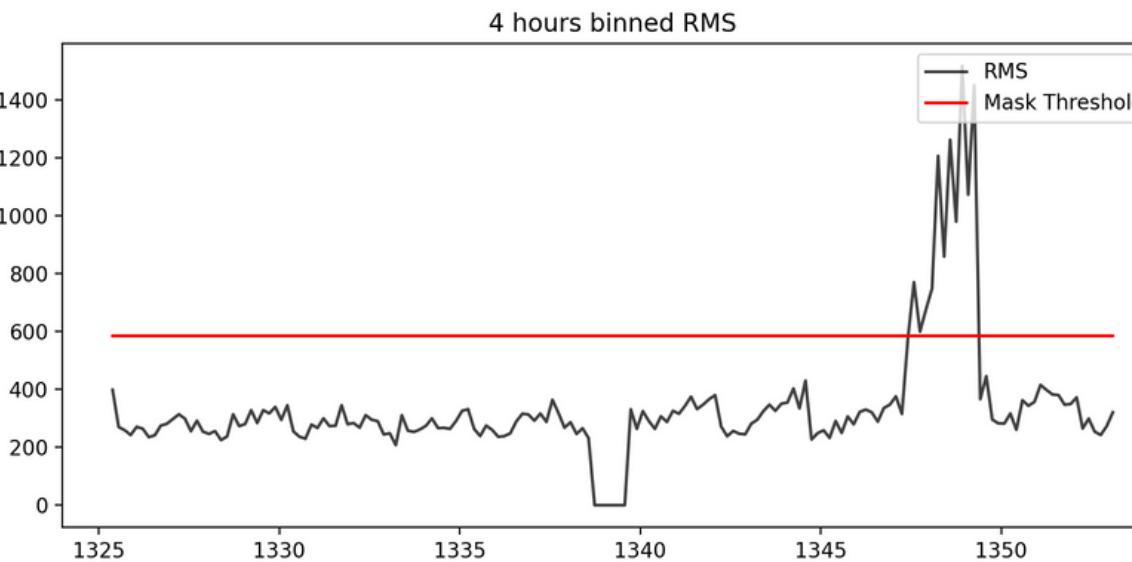
(1)

Prepare the  
data

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

```
Abrir ▾ F+ explore.yaml ~/Escritorio/EXOPLANETAS... Guardar ⌂ - ⌂ X
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
```

- **INITIAL\_HIGH\_RMS\_MASK: TRUE / FALSE**
- **INITIAL\_HIGH\_RMS\_THRESHOLD: 1.25 - 2**

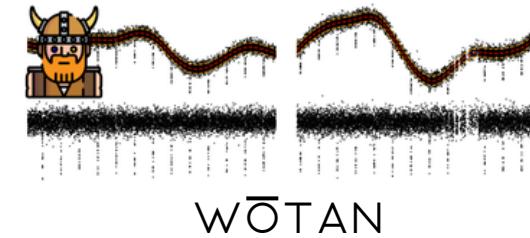


- Are there some noisy regions?



# The six SHERLOCK modules

Lightkurve



(1)

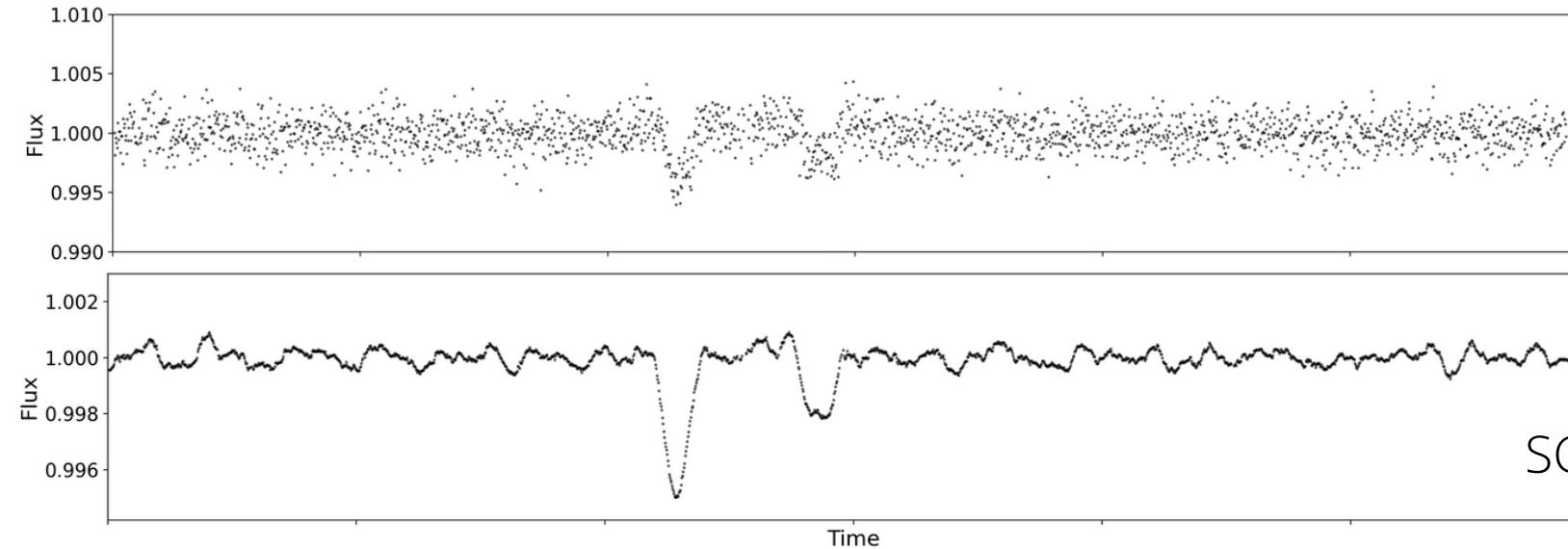
Prepare the  
data



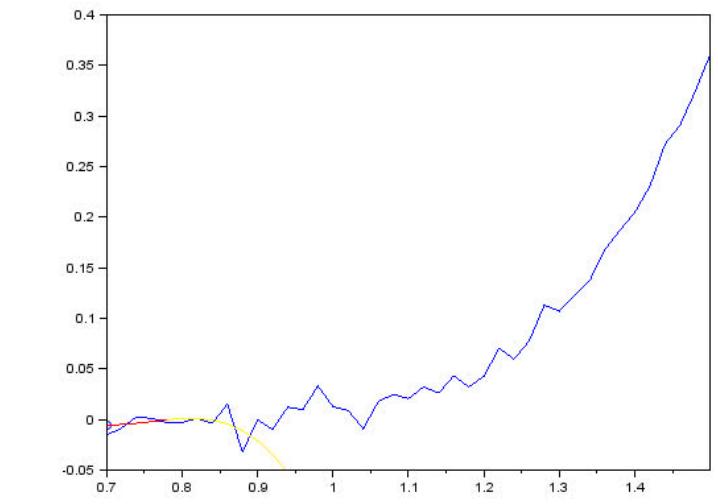
```
python3.10 -m sherlockpipe --properties explore.yaml --explore
```

```
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
```

- INITIAL\_SMOOTH\_ENABLED: TRUE/FALSE



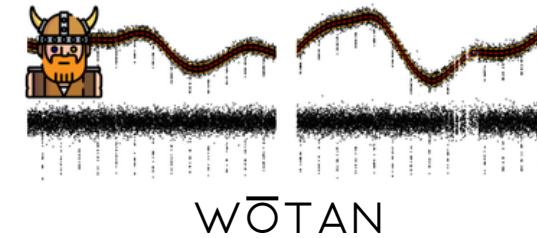
Savitsky-Golay  
filter



Similar SDEs but increase the SNR significantly!

# The six SHERLOCK modules

Lightkurve



(1)

Prepare the  
data



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

```
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
```

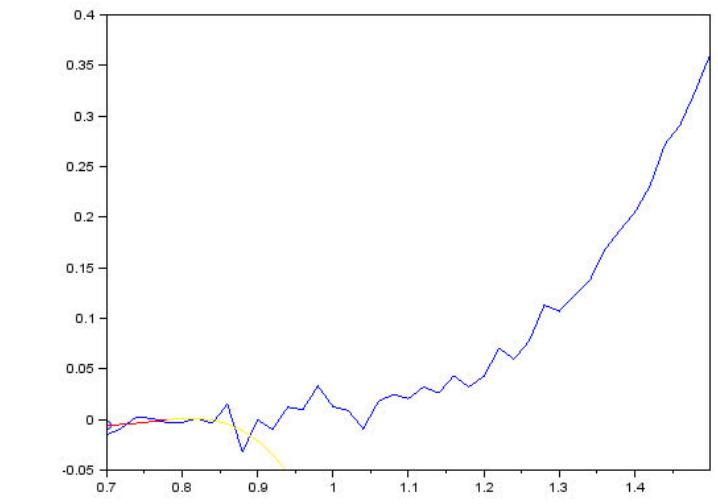
- INITIAL\_SMOOTH\_ENABLED: TRUE/FALSE



sherlock\_algorithm.ipynb



Savitsky-Golay  
filter

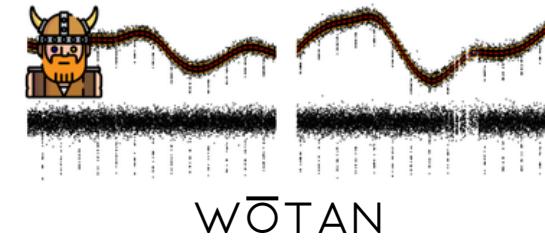


SG

Similar **SDEs** but increase the **SNR** significantly!

# The six SHERLOCK modules

Lightkurve



(1)

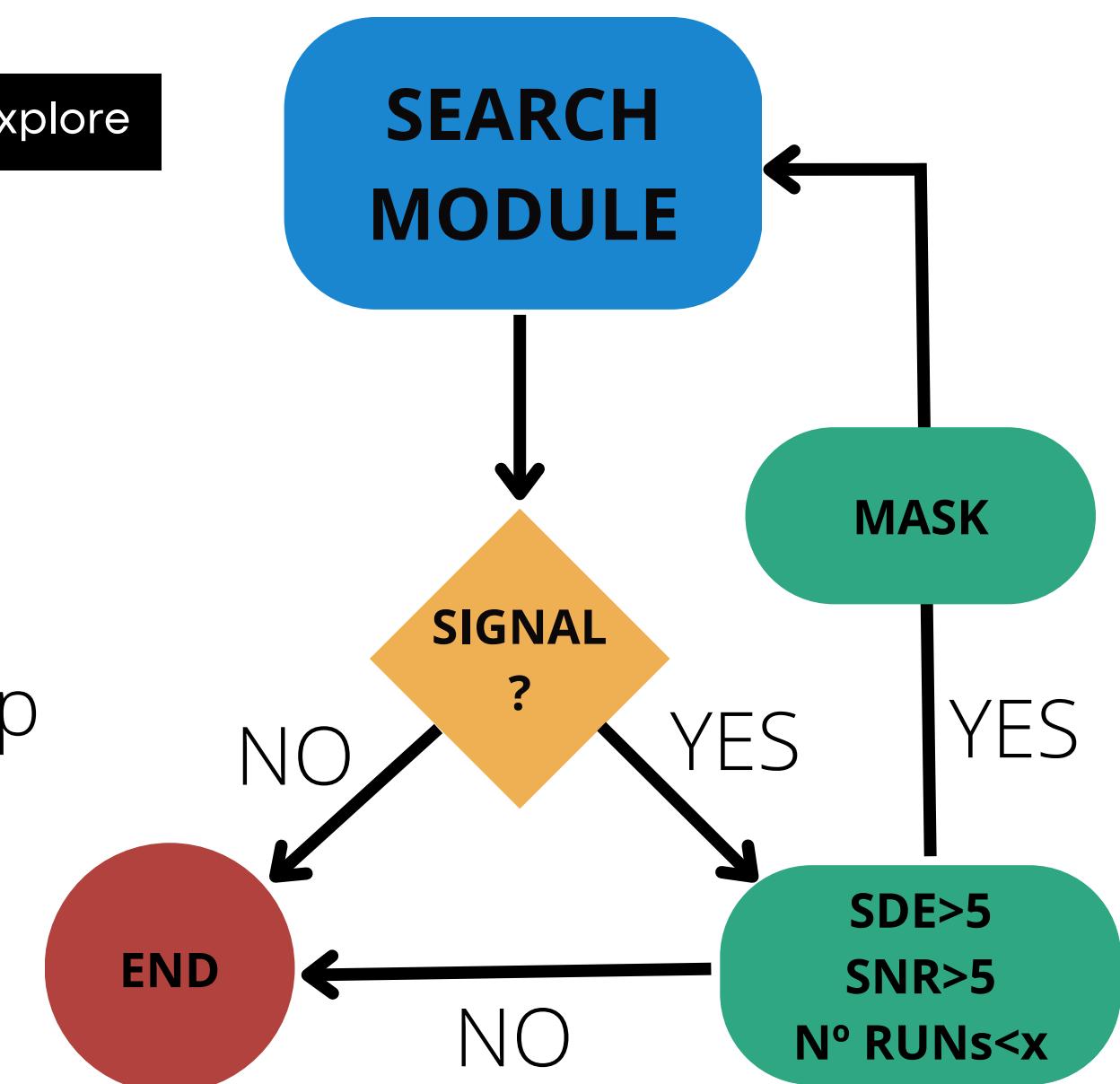
Prepare the  
data

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

```
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
```

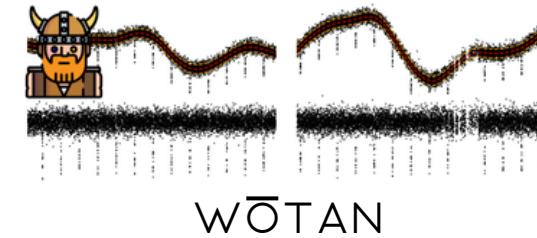
- MAX\_RUNS: 1-5
- SNR\_MIN: 5
- SDE\_MIN: 5

Searching-and-masking loop



# The six SHERLOCK modules

Lightkurve



(1)

Prepare the  
data



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

- DETREND\_CORES: [NUMBER OF CORES YOU WANT TO USE]
- CPU\_CORES: [NUMBER OF CORES YOU WANT TO USE]
- UPDATE\_OIS: TRUE/FALSE

```
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
```

# The six SHERLOCK modules



(1)

# Prepare the data

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

- **DETREND\_CORES:** [NUMBER OF CORES YOU WANT TO USE]
- **CPU\_CORES:** [NUMBER OF CORES YOU WANT TO USE]
- **UPDATE\_OIS:** TRUE/FALSE

```
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
```

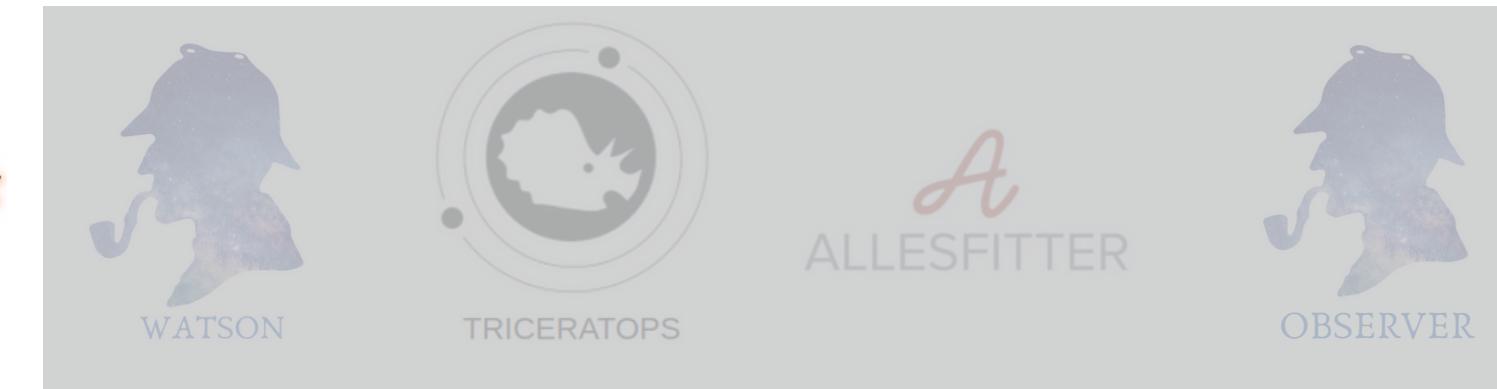
# AND MANY MORE...

<https://github.com/iaa-so-training/sherlock-tutorial/blob/main/Yaml%20examples/properties.yaml>

# The six SHERLOCK modules



Search for  
candidates



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

# The six SHERLOCK modules



# Transit Lease 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  
WOTAN

(2)

Search for candidates



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

A screenshot of a terminal window titled "TOI270.yaml". The window contains a block of YAML configuration code. The code defines a target named "TIC 259377017" with various parameters like "MODE: GLOBAL", "SECTORS: [3,4,5]", and "PERIOD\_MIN: 1.0". It also specifies "DETREND\_L\_MIN: 0.2" and "DETREND\_L\_MAX: 1.2". The file ends with "UPDATE\_OIS: True". At the bottom of the terminal, there are status indicators: "YAML", "Anchura del tabulador: 8", "Ln 1, Col 1", and "INS".

```
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  
WOTAN

(2)

Search for candidates



```
python3.10 -m sherlockpipe --properties xxxx.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
```

YAML Anchura del tabulador: 8 Ln 1, Col 1 INS

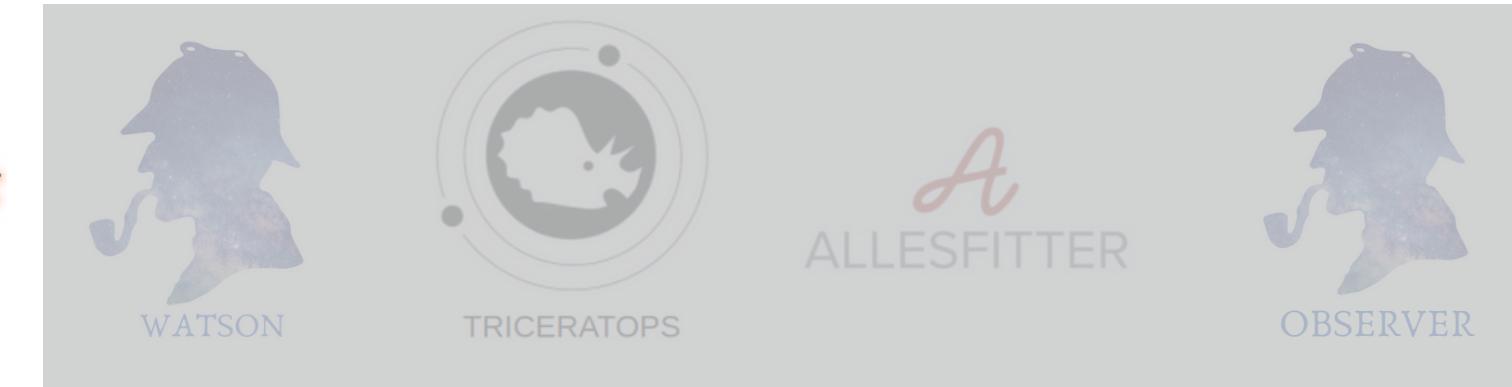
SHERLOCK will search for planets over the  
detrended light curves + PCD\_SAP

10+1 !!

# The six SHERLOCK modules



Search for  
candidates



```
python3.10 -m sherlockpipe --properties xxxx.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
YAML ▾ Anchura del tabulador: 8 ▾ Ln 1, Col 1 ▾ INS
```

**SHERLOCK** will search for planets  
over the  
**detrended light curves + PCD\_SAP**



shearching\_planets.ipynb

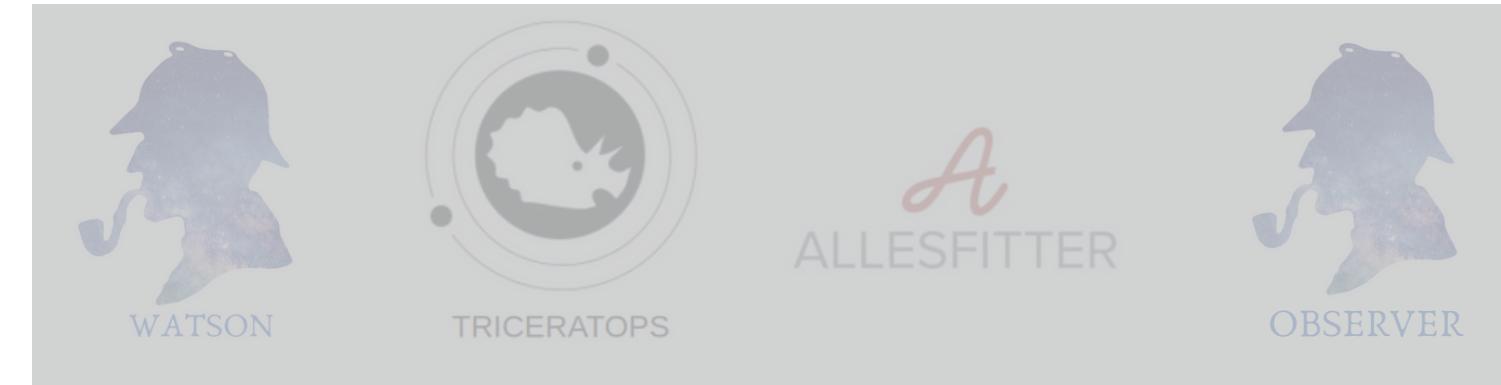
# The six SHERLOCK modules



Transit Least Squares  
WOTAN

(2)

Search for candidates



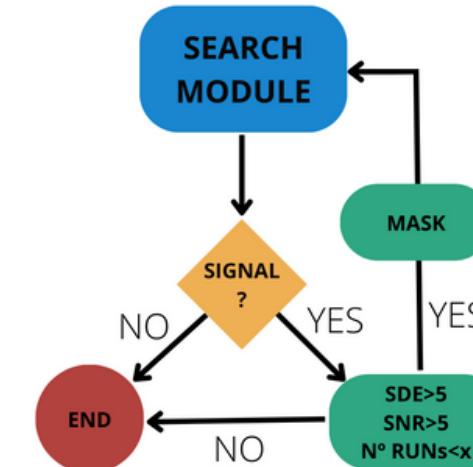
```
python3.10 -m sherlockpipe --properties xxxx.yaml
```

```
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
YAML ▾ Anchura del tabulador: 8 ▾ Ln 1, Col 1 ▾ INS
```

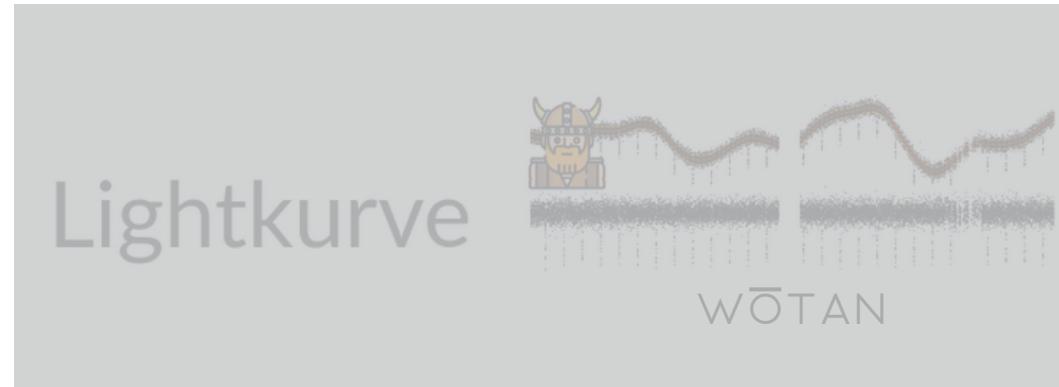
3 !!

SHERLOCK will search for planets  
over the  
detrended light curves + PCD\_SAP  
a number of times

Searching-and-masking loop



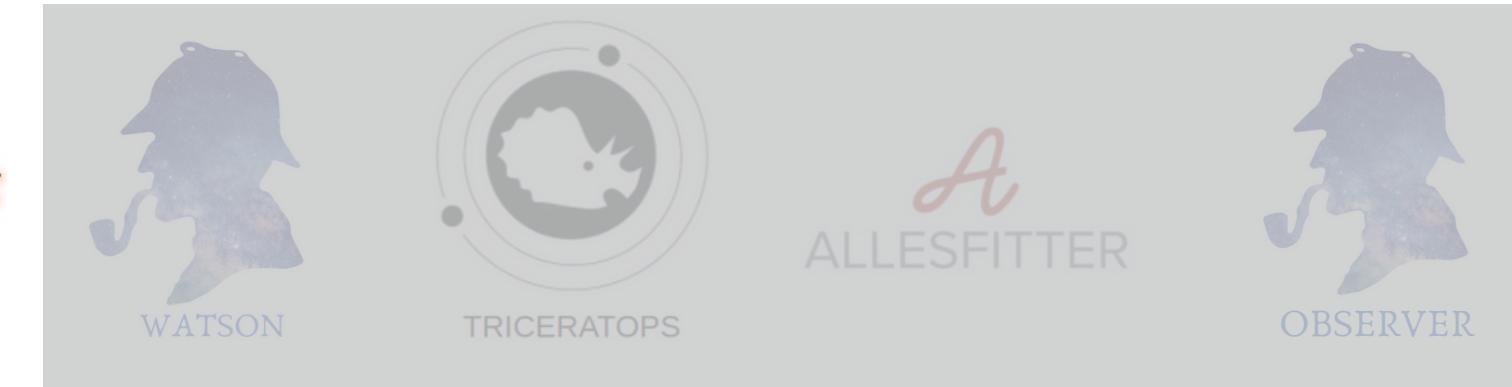
# The six SHERLOCK modules



Transit Least Squares  
WOTAN

(2)

Search for candidates



```
python3.10 -m sherlockpipe --properties xxxx.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
YAML ▾ Anchura del tabulador: 8 ▾ Ln 1, Col 1 ▾ INS
```

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



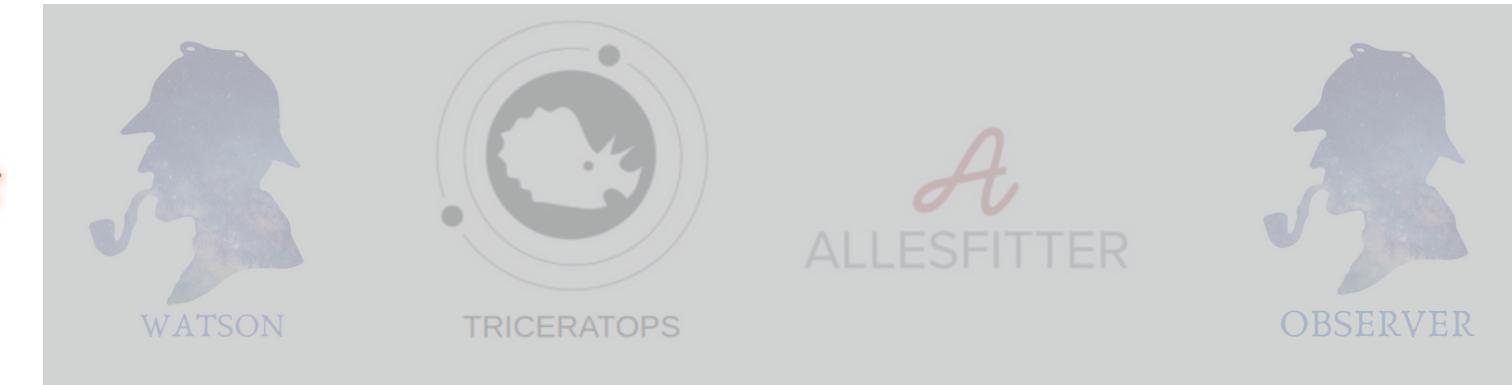
# The six SHERLOCK modules



Transit Least Squares  
WOTAN

(2)

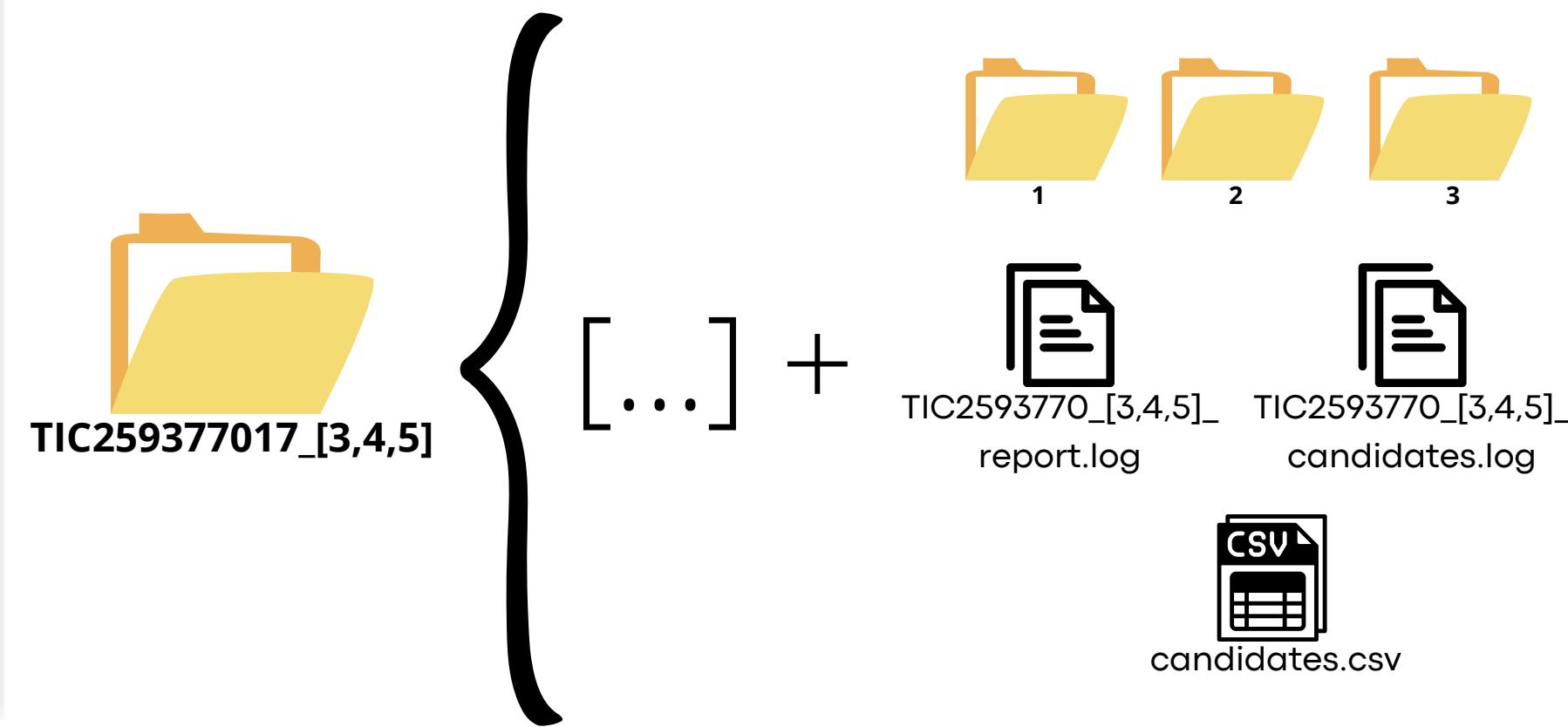
Search for candidates



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

```
Abrir ▾ Guardar ×
TOI270.yaml
~/Escritorio/EXOPL...

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
YAML ▾ Anchura del tabulador: 8 ▾ Ln 1, Col 1 ▾ INS
```



Results of each run

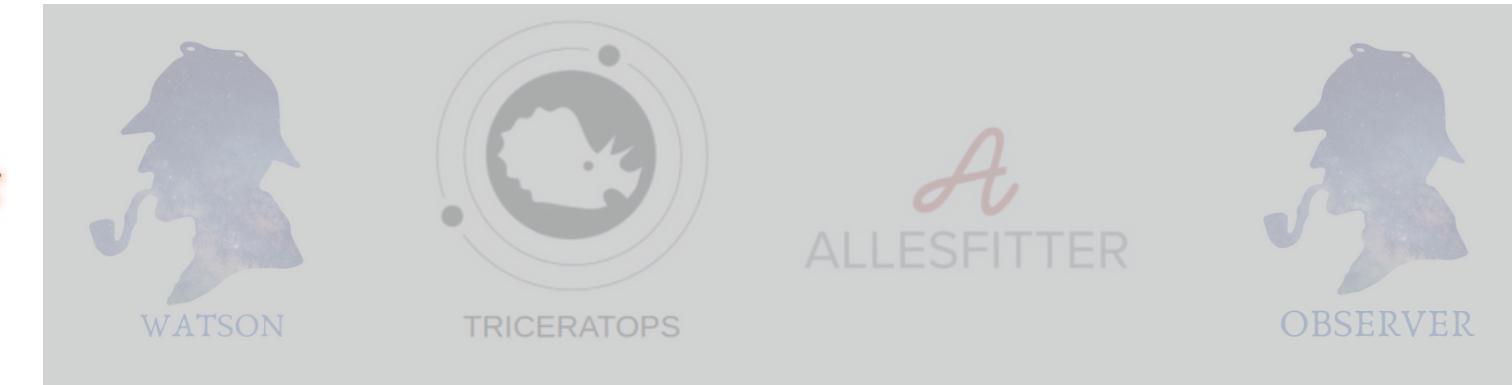
# The six SHERLOCK modules



Transit Least Squares  
WOTAN

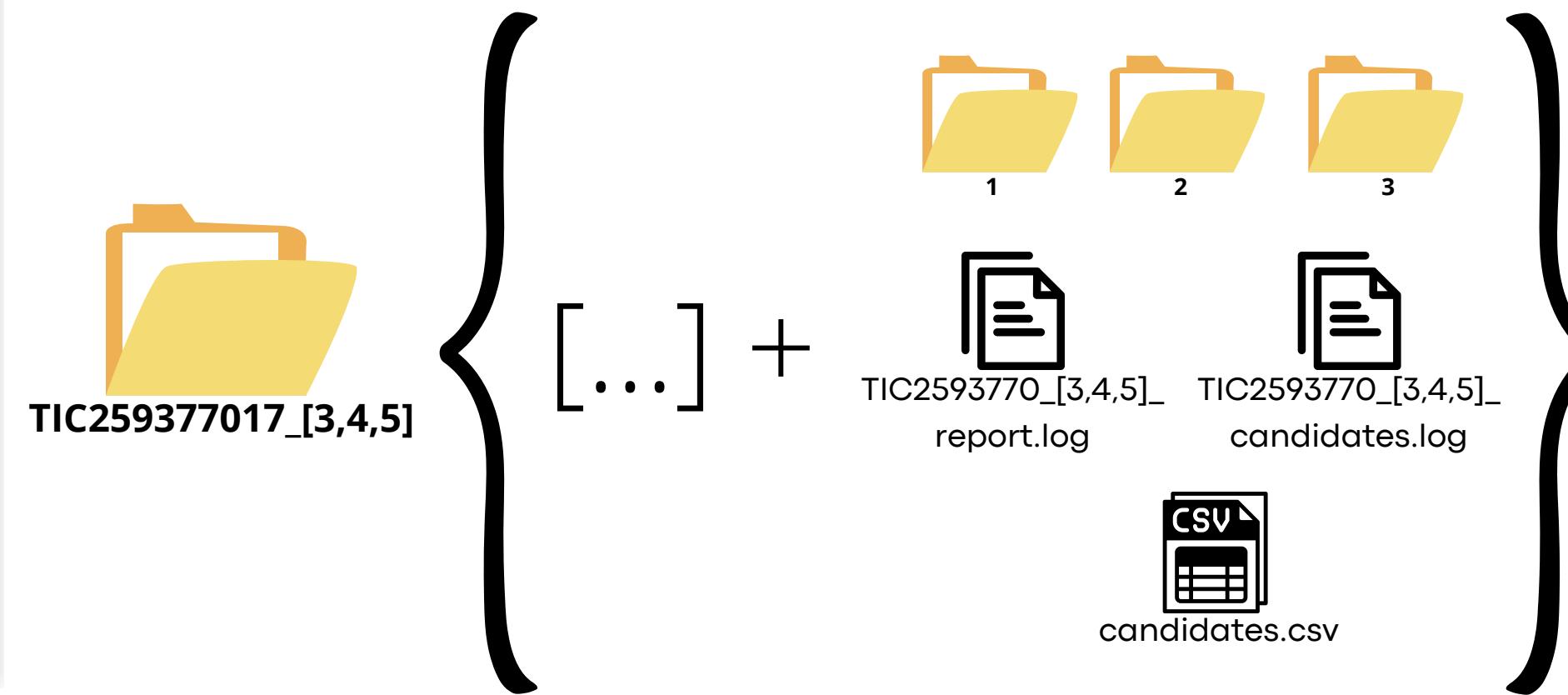
(2)

Search for candidates



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

```
Abrir ▾ Guardar ▾ X
TOI270.yaml
~/Escritorio/EXOPL...
1 TARGETS:
2 TIC 259377017:
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17 PERIOD_MIN: 1.0
18 PERIOD_MAX: 15
19 UPDATE_OIS: True
20
YAML ▾ Anchura del tabulador: 8 ▾ Ln 1, Col 1 ▾ INS
```



Have a quick look at the results!



TIC2593770\_[3,4,5]\_  
report.log

TIC2593770\_[3,4,5]\_  
candidates.log

candidates.csv

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

Let's explore the files y together!

# The six SHERLOCK modules

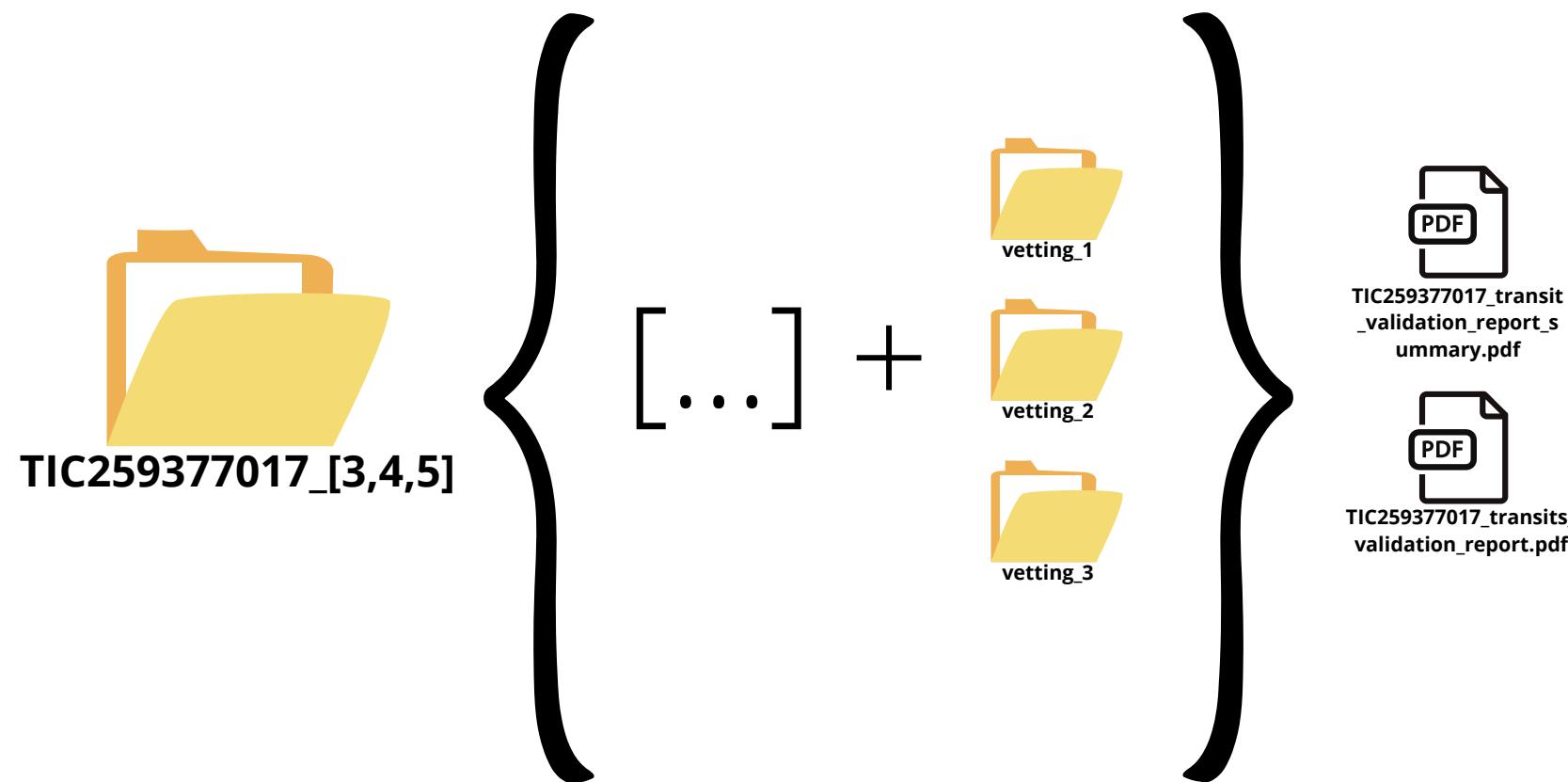


```
python3.10 -m sherlockpipe.vet --candidate x
```

x=1, 2, 3 ...

(3)

Vetting



- 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 you  
together!

# The six SHERLOCK modules

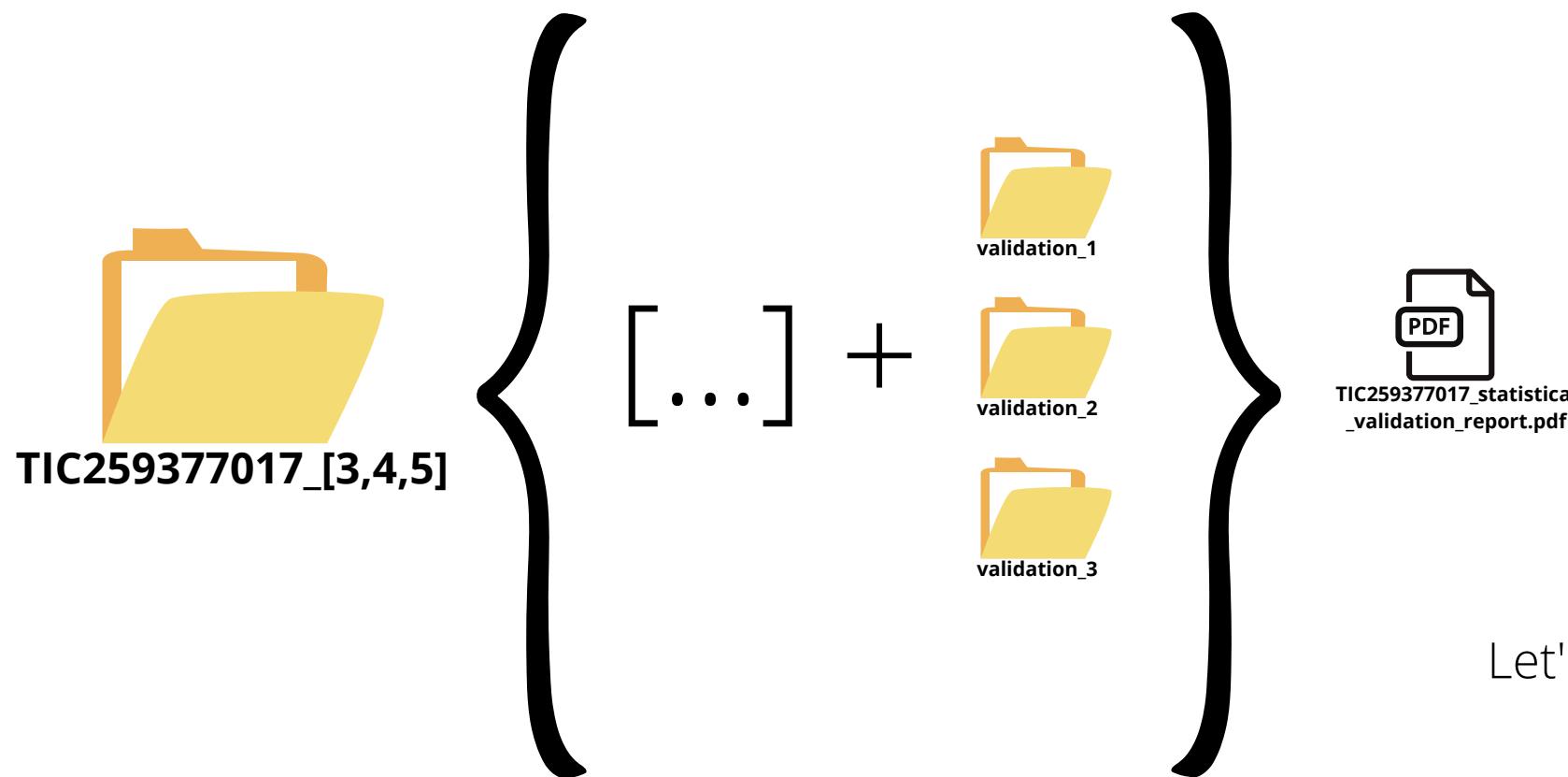


```
python3.10 -m sherlockpipe.validate --candidate x
```

x=1, 2, 3 ...

(4)

Statistical validation



Let's explore the files together!

- Is there any other astrophysical scenario producing the signal?

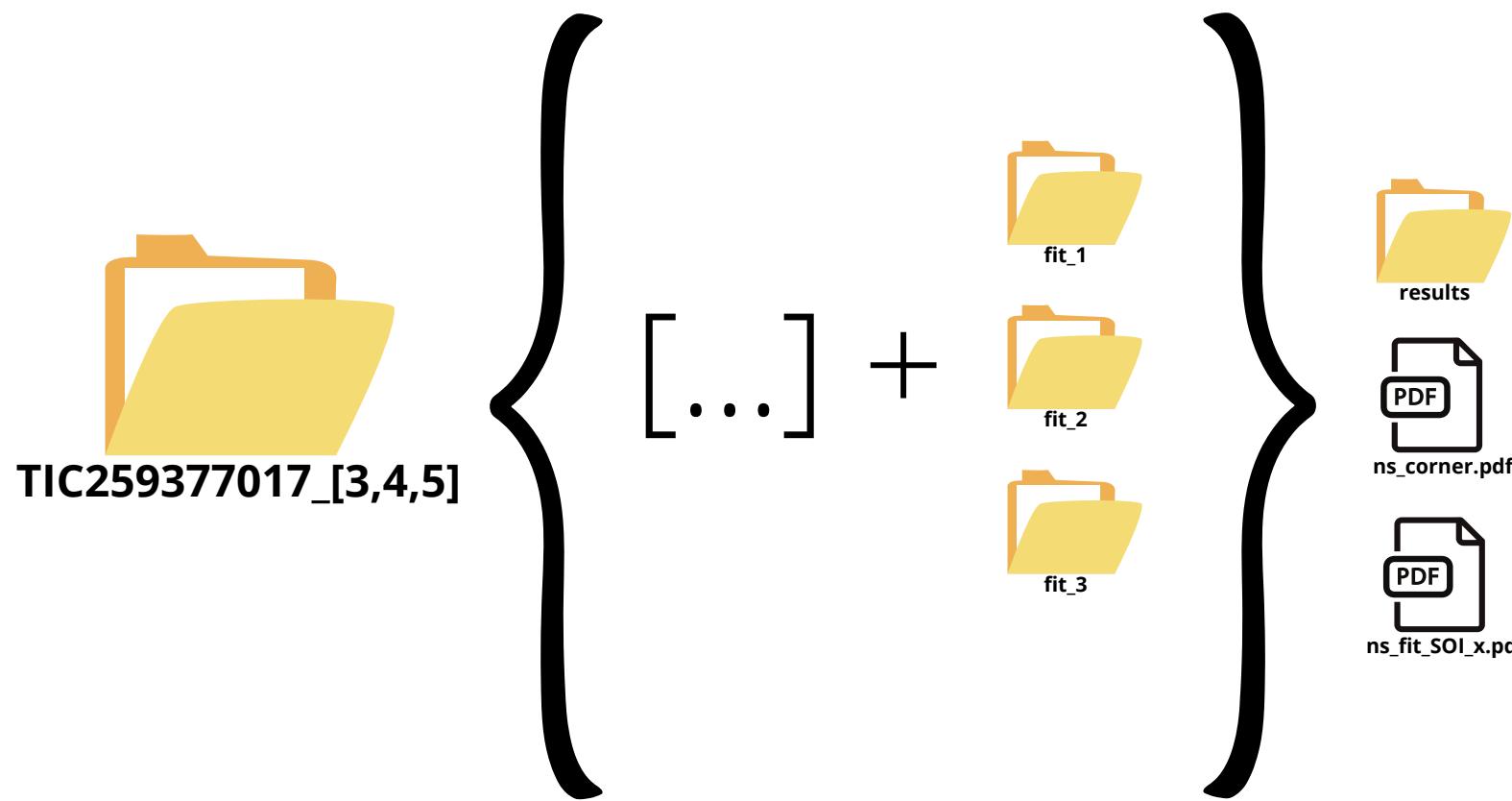
| Scenarios Tested by TRICERATOPS |                                                                                                    |
|---------------------------------|----------------------------------------------------------------------------------------------------|
| Scenario                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

# The six SHERLOCK modules



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

x=1, 2, 3 ...



Predicted transit time

Epoch

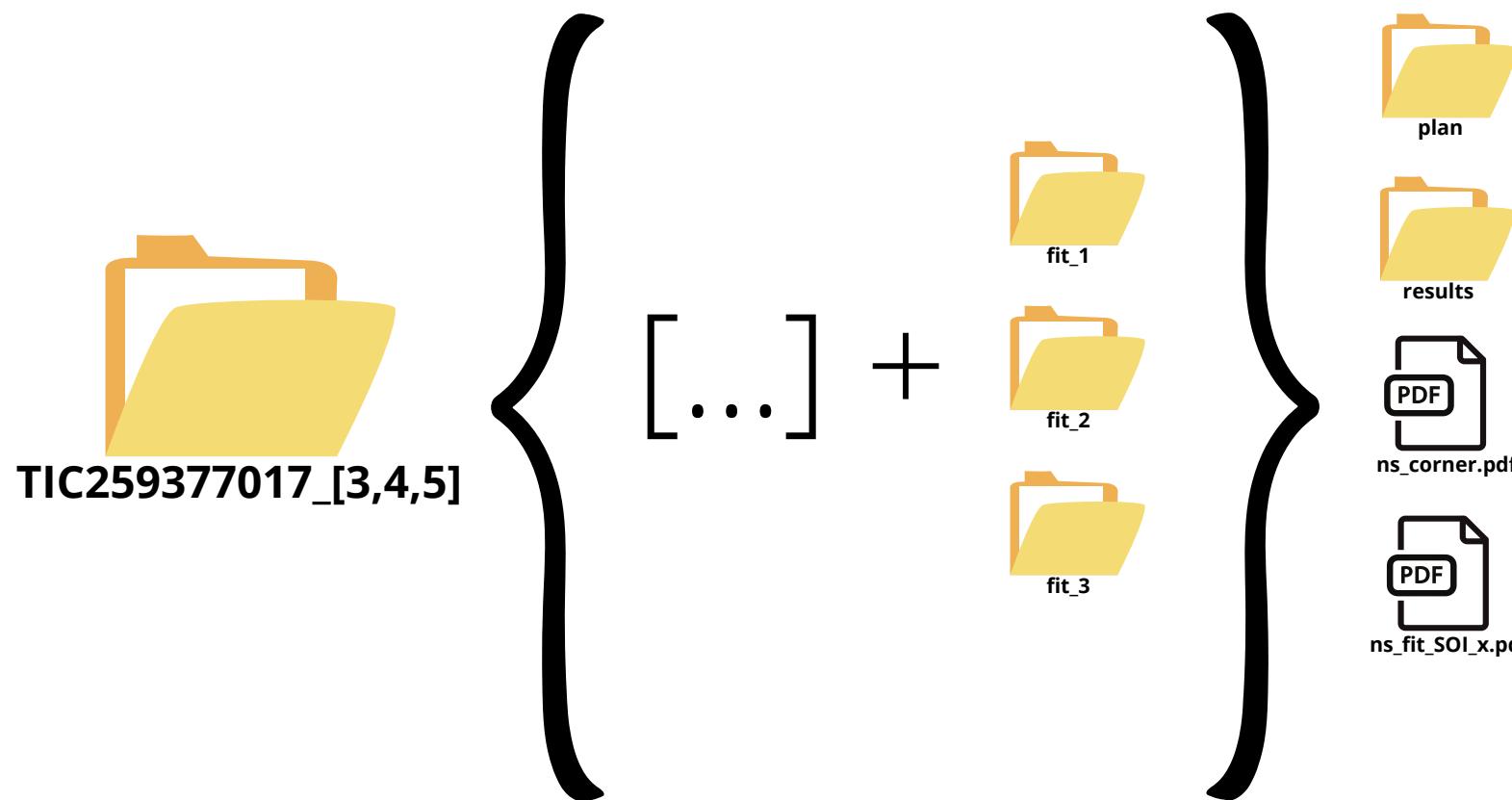
nº cycles

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

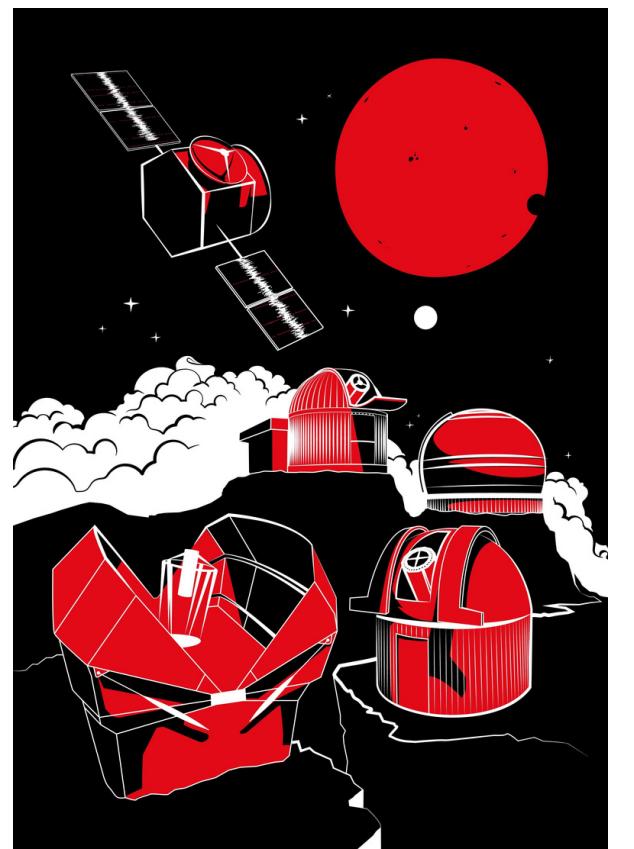


List of the observatories from where you would like to observe the candidate

| name               | tz         | lat      | lon  | alt |
|--------------------|------------|----------|------|-----|
| 2 Trappist-South   | ,,-29.2563 | -70.738  | 2375 |     |
| 3 Trappist-North   | ,,31.2061  | -7.8664  | 2751 |     |
| 4 #SPECULOOS-South | ,,-24.6272 | -70.4042 | 2518 |     |

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

 jupyter tess\_lightcurves.ipynb

 jupyter detrending\_lightcurves.ipynb **EXTRA!**

 jupyter sherlock\_algorithm.ipynb

 jupyter searching\_planets.ipynb **EXTRA!**

 jupyter searching\_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



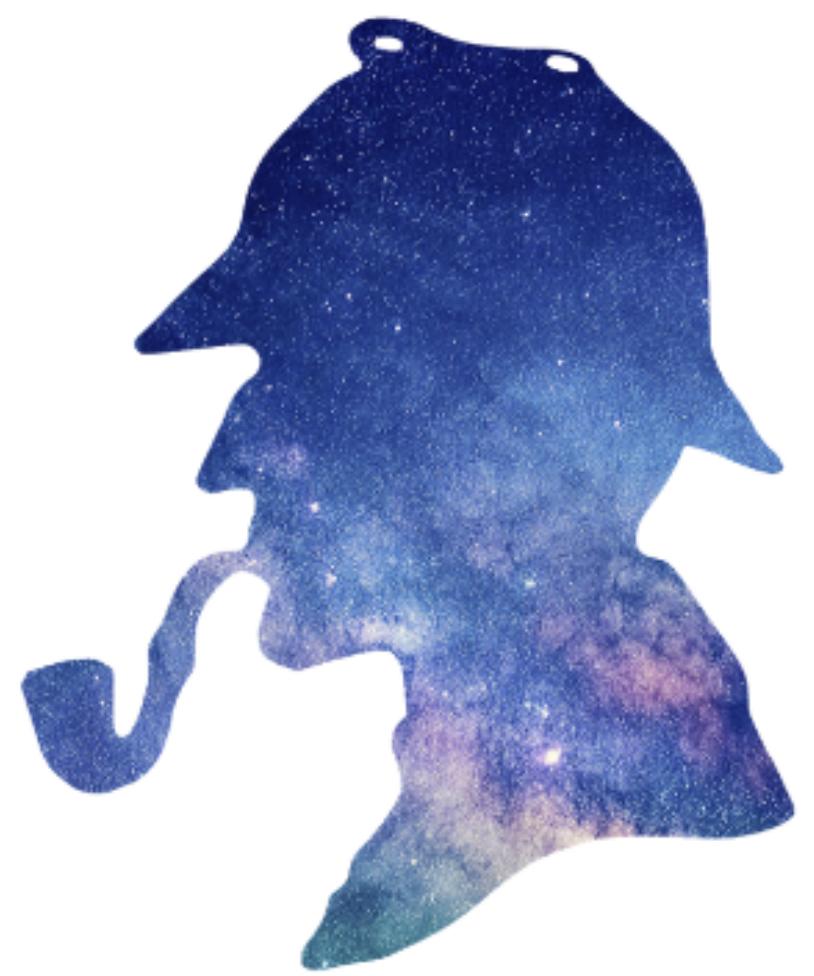
You only need to execute 6 command lines



Is designed to run on a computational server



Strong support and a Slack channel for help



THANKS !