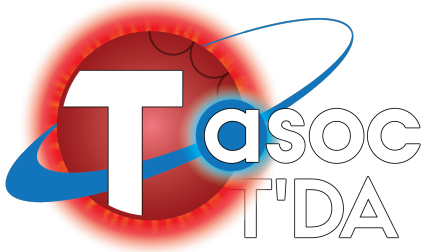
Observing the brightest stars with TESS

Tim White
Research School of Astronomy and Astrophysics, Australian National University
→ Sydney Institute for Astronomy, University of Sydney



THE UNIVERSITY OF SYDNEY

STELLAR ASTROPHYSICS CENTRE

Australian National University

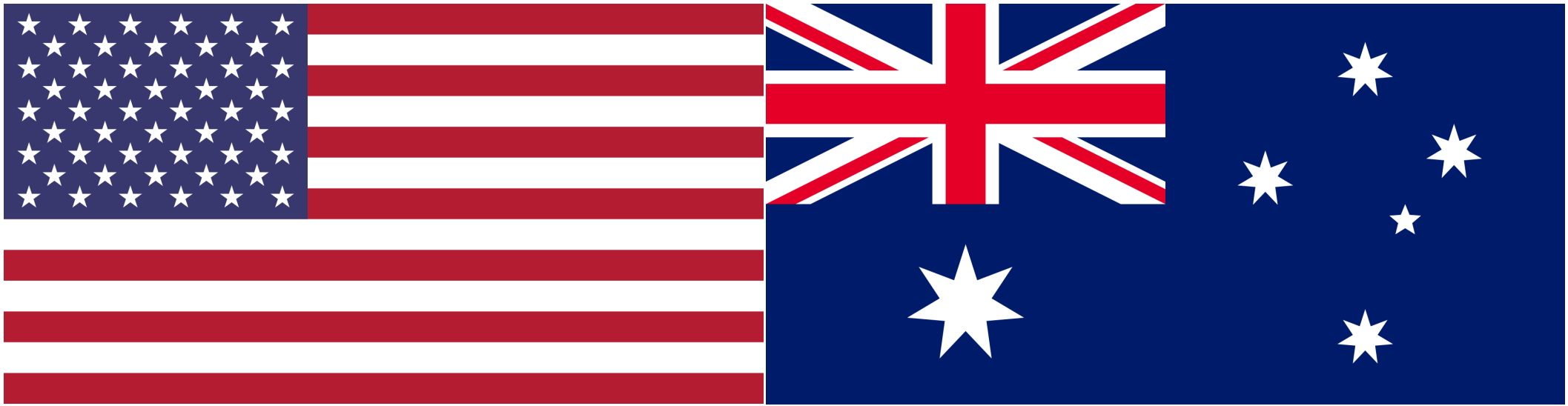
TESS Science Conference I
Cambridge, MA, USA
31 July 2019

Will Waalkes
@AstroWillWaal

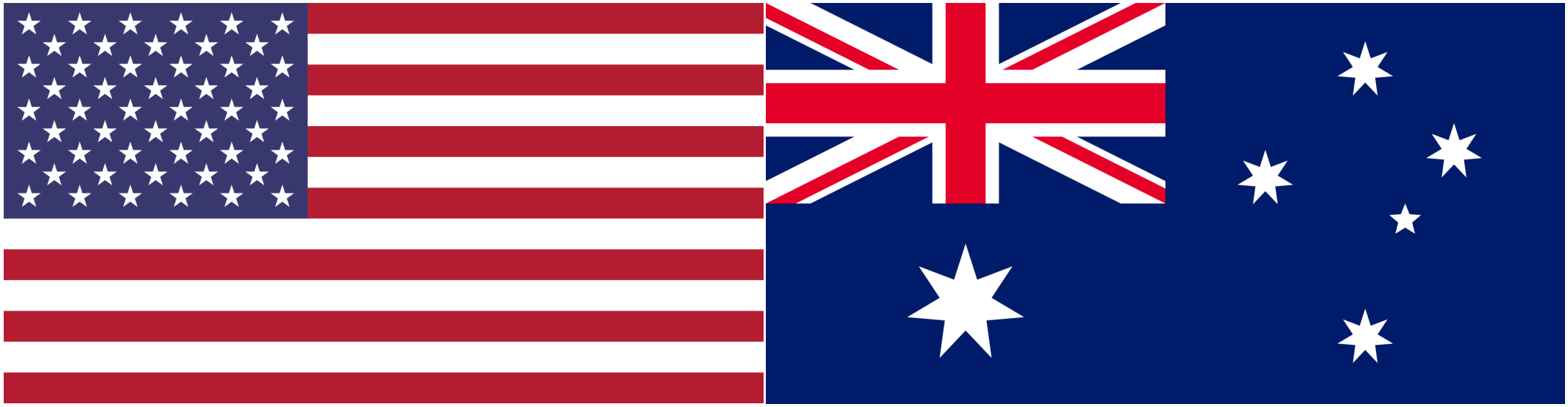
Idk who Tim is but he must have been pretty important to get a whole university named after him

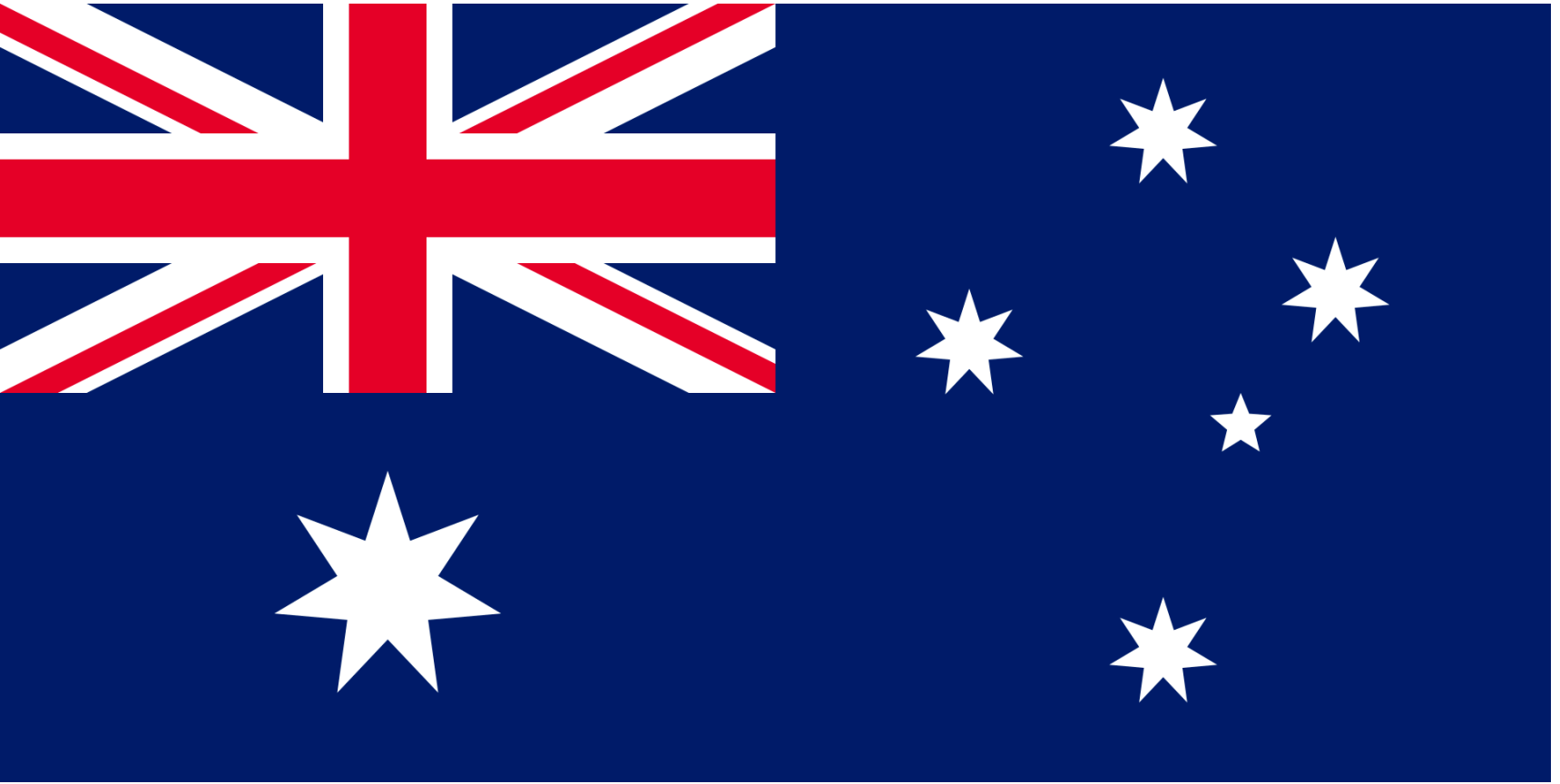
#TESScon

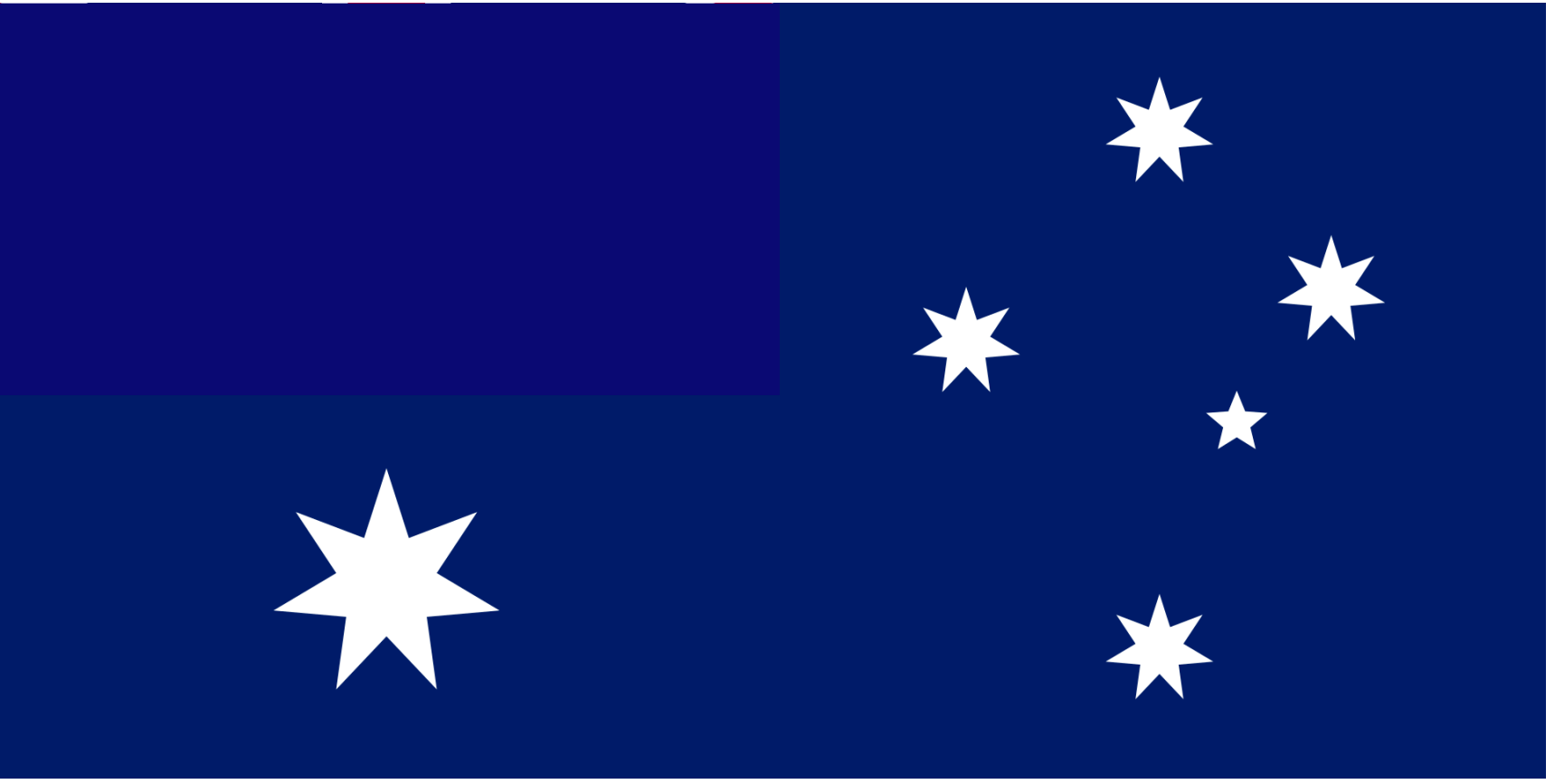
← **Tweet**

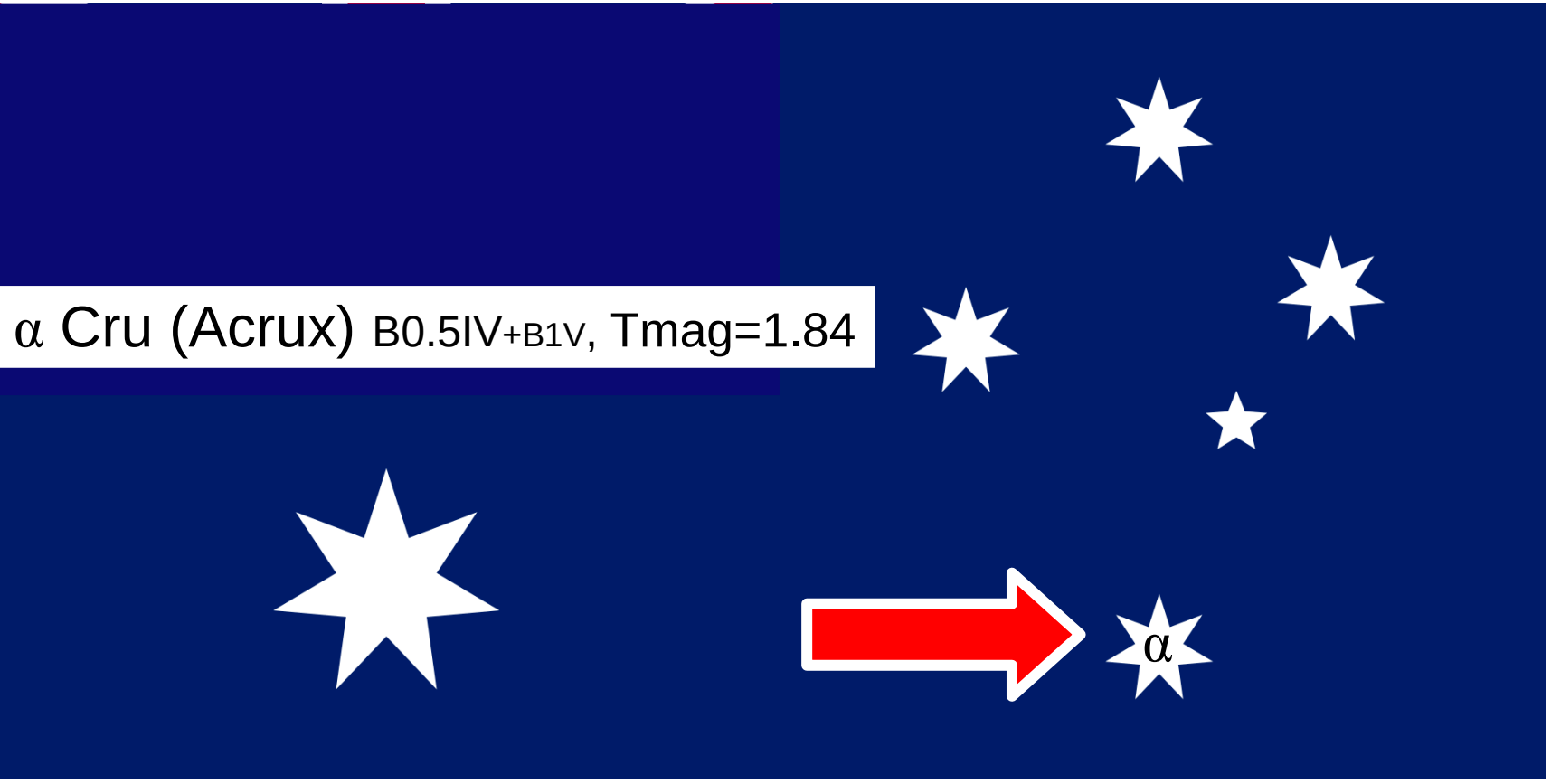


Observed in TESS Sector 11!



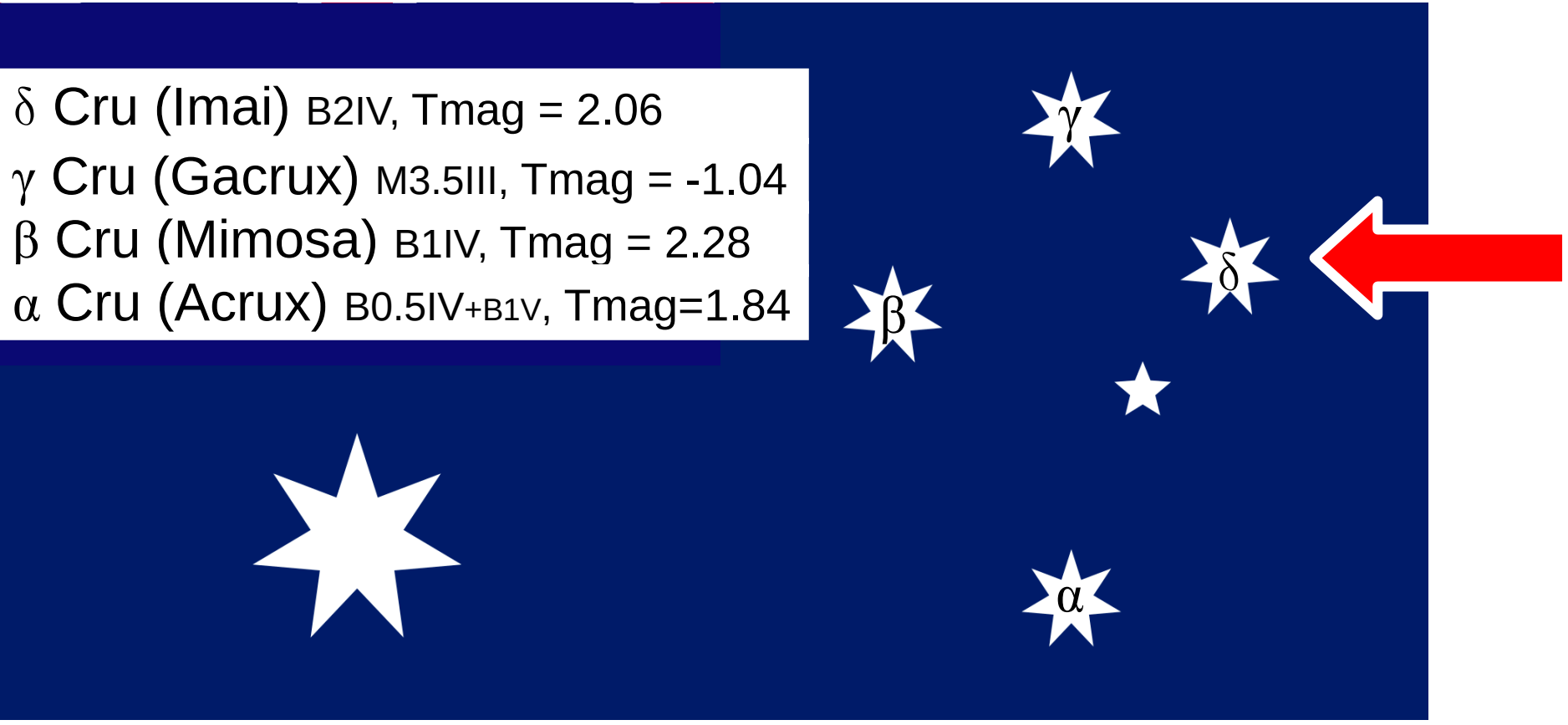





α Cru (Acrux) B0.5IV+B1V, Tmag=1.84
α


β Cru (Mimosa) B1IV, Tmag = 2.28
α Cru (Acrux) B0.5IV+B1V, Tmag=1.84
β
α


γ Cru (Gacrux) M3.5III, Tmag = -1.04
β Cru (Mimosa) B1IV, Tmag = 2.28
α Cru (Acrux) B0.5IV+B1V, Tmag=1.84
γ
β
α


δ Cru (Imai) B2IV, Tmag = 2.06
γ Cru (Gacrux) M3.5III, Tmag = -1.04
β Cru (Mimosa) B1IV, Tmag = 2.28
α Cru (Acrux) B0.5IV+B1V, Tmag=1.84
γ
δ
β
α

ε Cru (Ginan) K3III, Tmag = 2.31

δ Cru (Imai) B2IV, Tmag = 2.06

γ Cru (Gacrux) M3.5III, Tmag = -1.04

β Cru (Mimosa) B1IV, Tmag = 2.28

α Cru (Acrux) B0.5IV+B1V, Tmag=1.84

ε Cru (Ginan) K3III, Tmag = 2.31

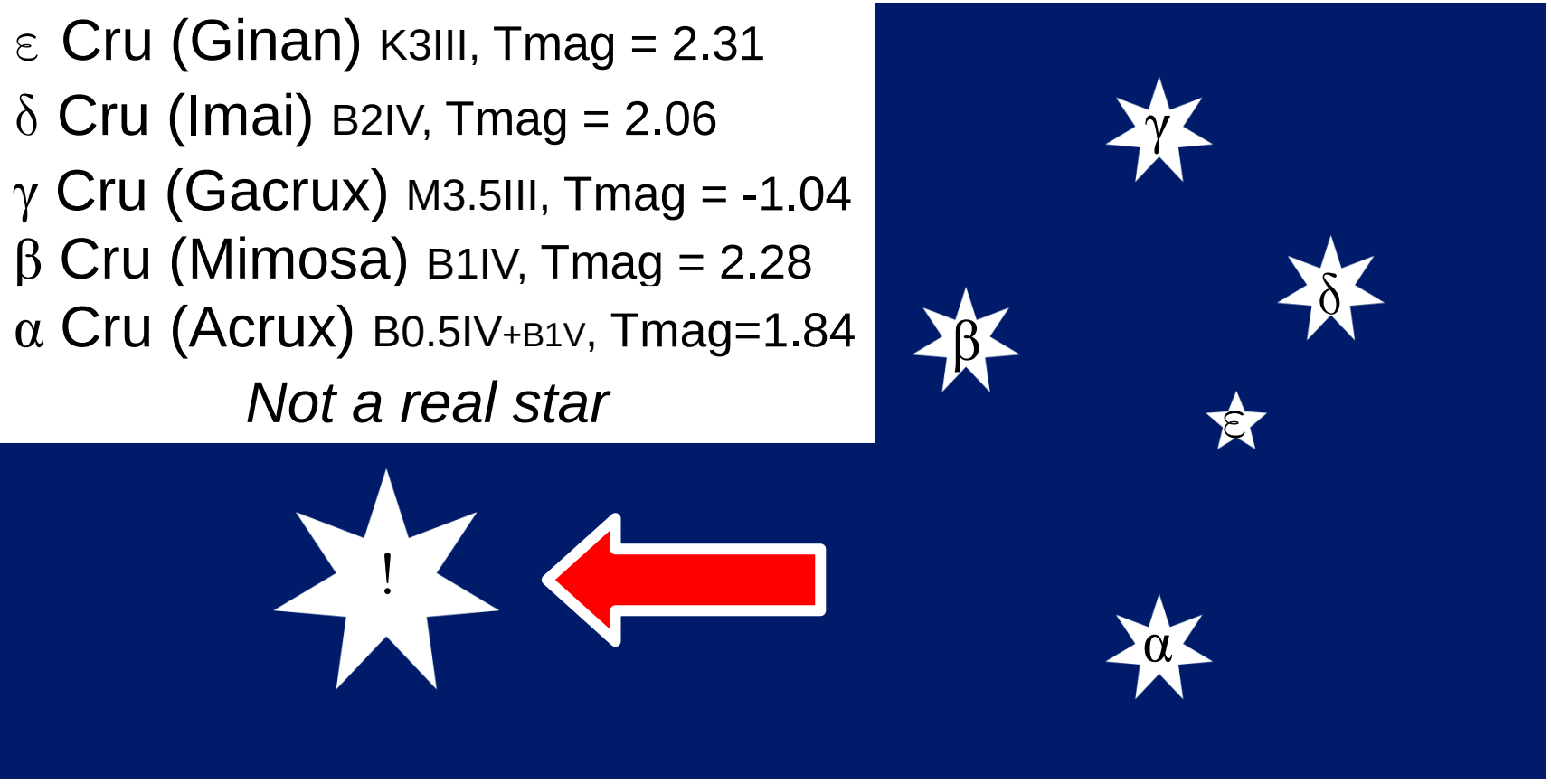
δ Cru (Imai) B2IV, Tmag = 2.06

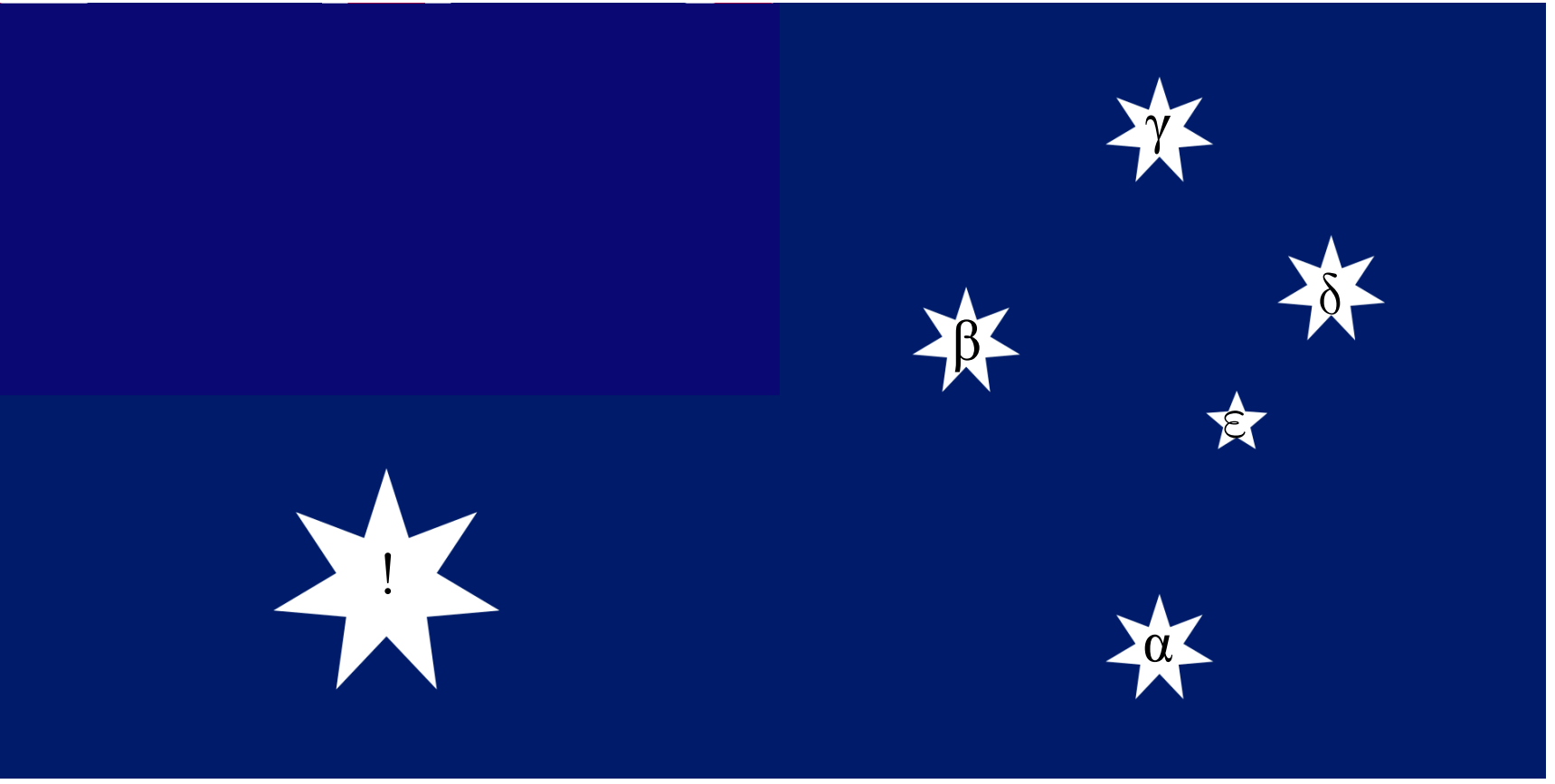
γ Cru (Gacrux) M3.5III, Tmag = -1.04

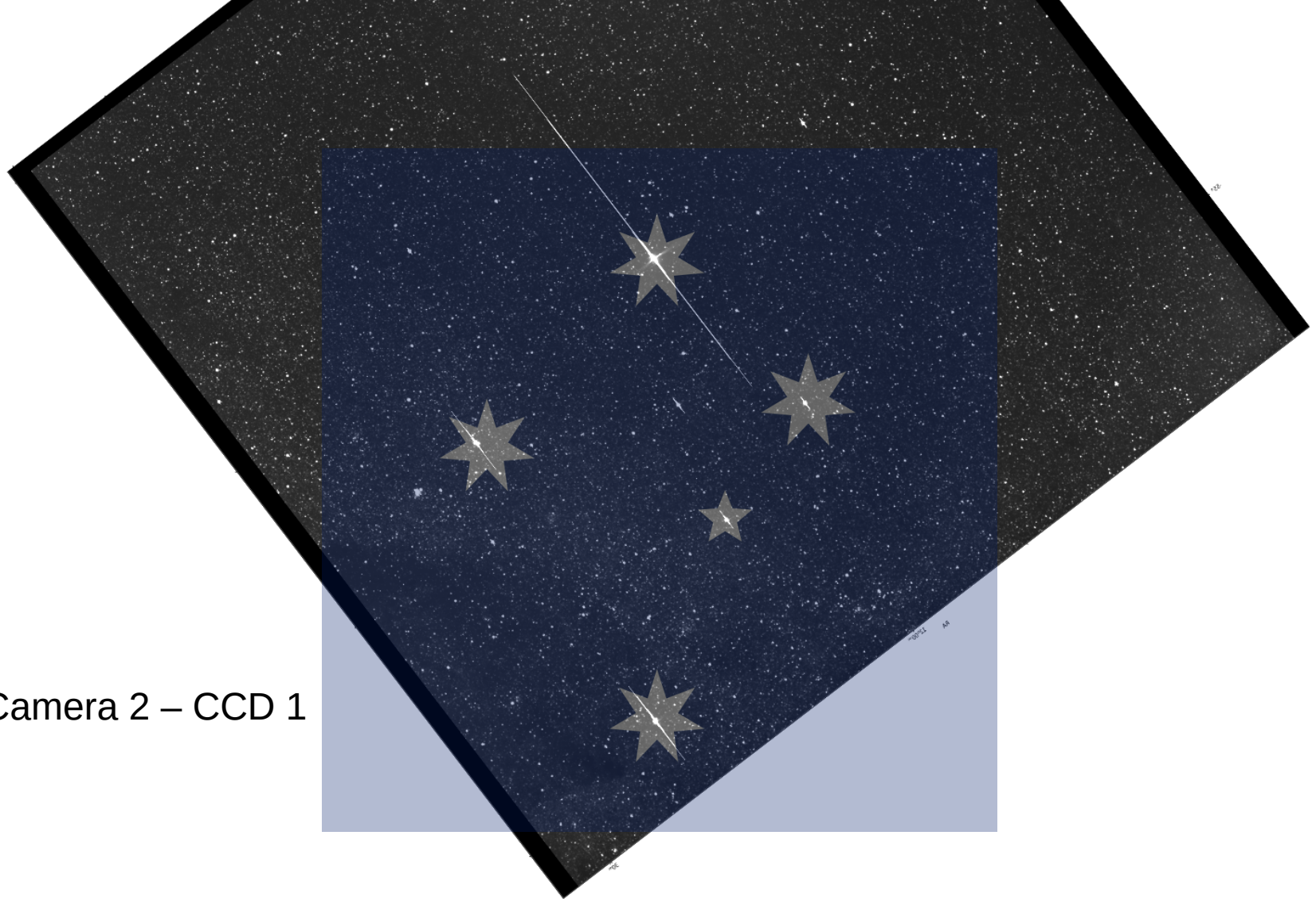
β Cru (Mimosa) B1IV, Tmag = 2.28

α Cru (Acrux) B0.5IV+B1V, Tmag=1.84

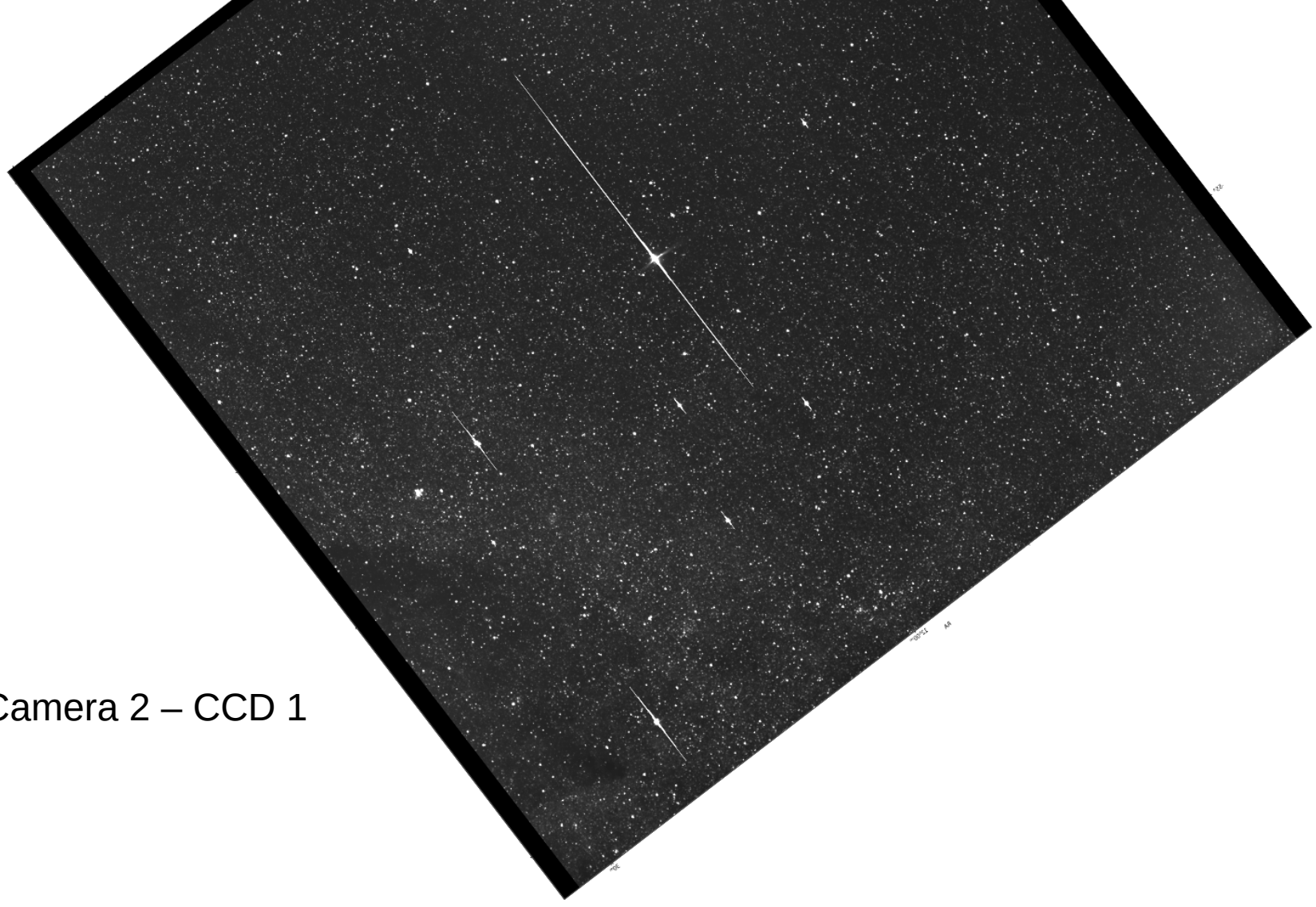
Not a real star



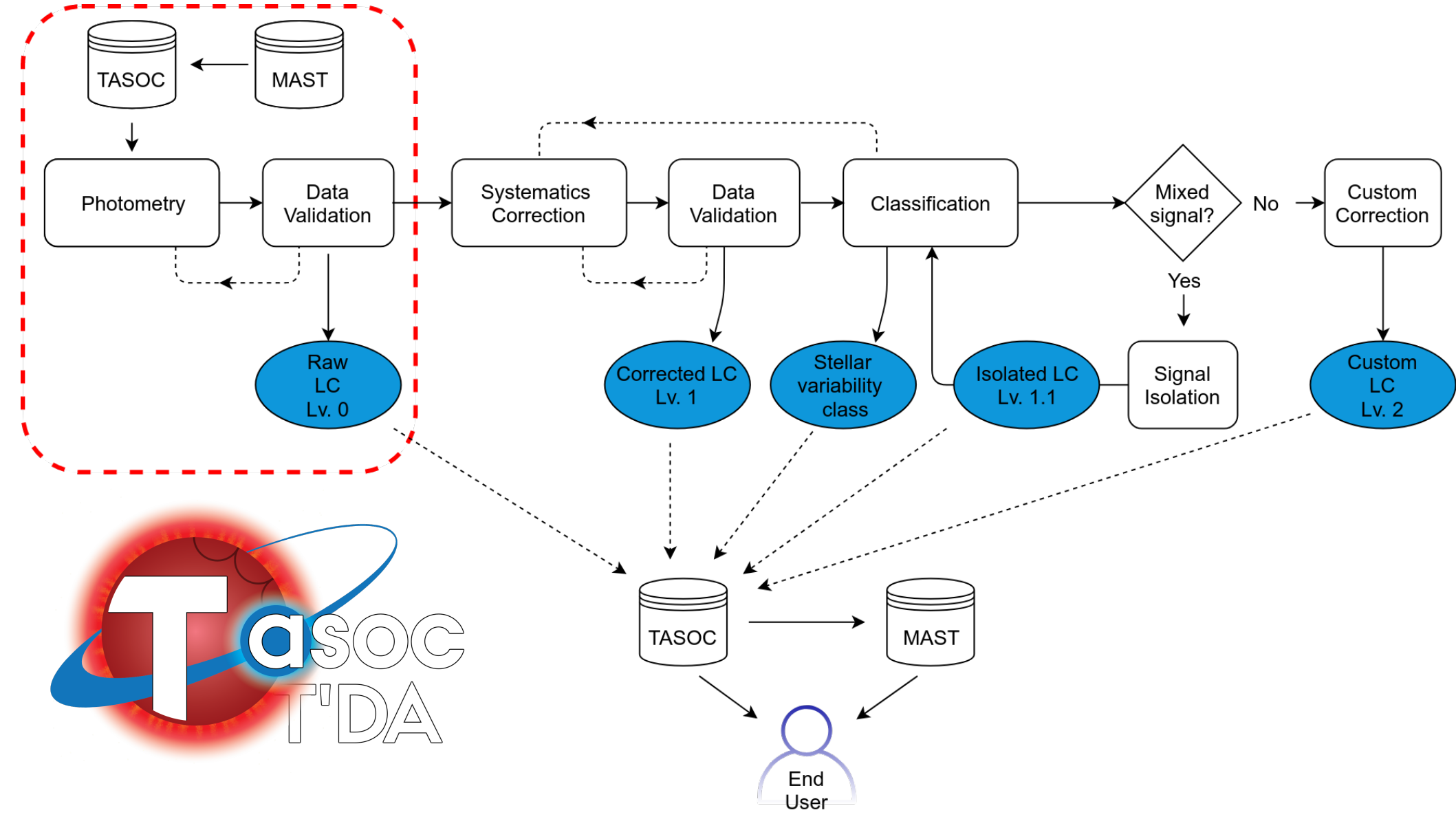

γ
δ
β
ε
!
α



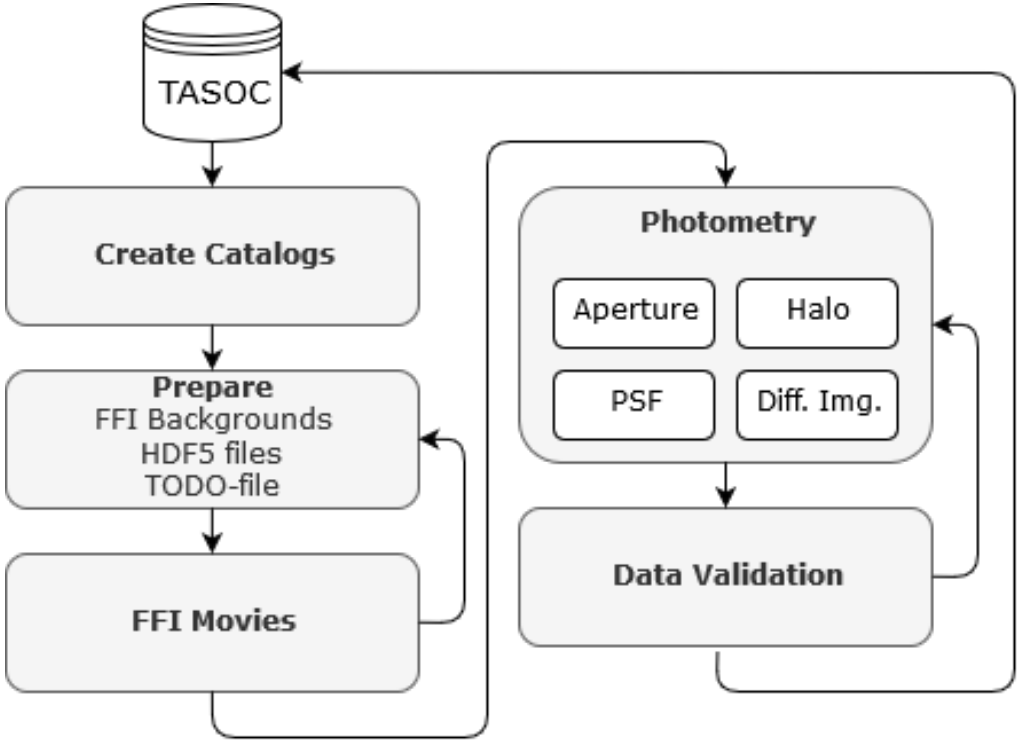
TESS Sector 11 – Camera 2 – CCD 1



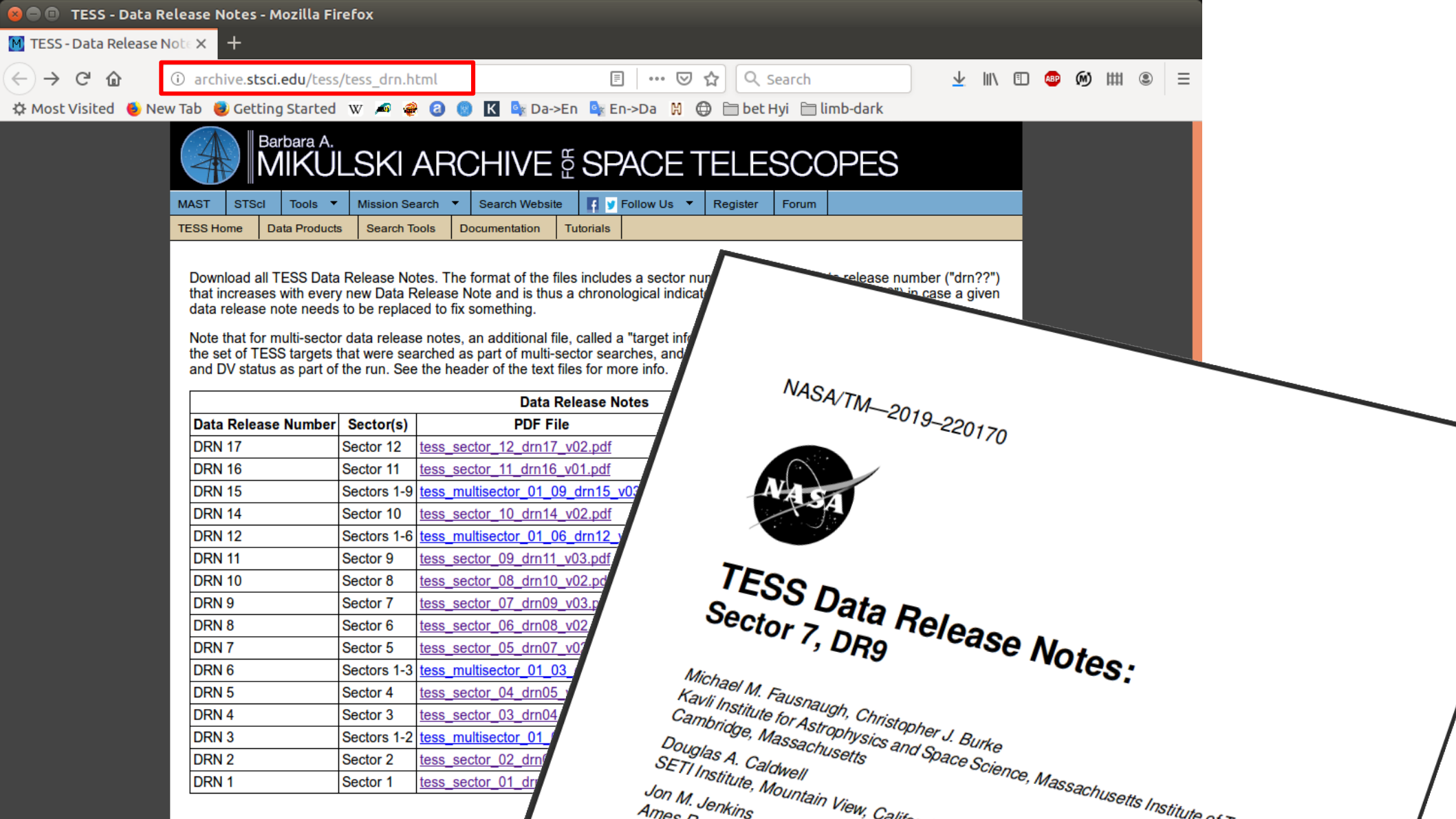
TESS Sector 11 – Camera 2 – CCD 1


TASOC
MAST
Photometry
Data Validation
Systematics Correction
Data Validation
Classification
Mixed signal?
No
Custom Correction
Yes
Raw LC Lv. 0
Corrected LC Lv. 1
Stellar variability class
Isolated LC Lv. 1.1
Signal Isolation
Custom LC Lv. 2
TASOC
MAST
End User

The TASOC Photometry Pipeline



Rasmus Handberg
Mikkel Lund
Jonas Hansen
Ben Pope
Oliver Hall
Carolina von Essen
+ the T'DA collaboration


TESS - Data Release Notes - Mozilla Firefox
TESS - Data Release Not
archive.stsci.edu/tess/tess_drn.html
Search
Most Visited
New Tab
Getting Started
Da->En
En->Da
bet Hyi
limb-dark
Barbara A.
MIKULSKI ARCHIVE FOR SPACE TELESCOPES
MAST
STScI
Tools
Mission Search
Search Website
Follow Us
Register
Forum
TESS Home
Data Products
Search Tools
Documentation
Tutorials
Download all TESS Data Release Notes. The format of the files includes a sector nu
release number ("drn??")
that increases with every new Data Release Note and is thus a chronological indicat
in case a given
data release note needs to be replaced to fix something.
Note that for multi-sector data release notes, an additional file, called a "target inf
the set of TESS targets that were searched as part of multi-sector searches, and
and DV status as part of the run. See the header of the text files for more info.
Data Release Notes
Data Release Number
Sector(s)
PDF File
DRN 17
Sector 12
tess_sector_12_drn17_v02.pdf
DRN 16
Sector 11
tess_sector_11_drn16_v01.pdf
DRN 15
Sectors 1-9
tess_multisector_01_09_drn15_v0
DRN 14
Sector 10
tess_sector_10_drn14_v02.pdf
DRN 12
Sectors 1-6
tess_multisector_01_06_drn12_
DRN 11
Sector 9
tess_sector_09_drn11_v03.pdf
DRN 10
Sector 8
tess_sector_08_drn10_v02.pd
DRN 9
Sector 7
tess_sector_07_drn09_v03.p
DRN 8
Sector 6
tess_sector_06_drn08_v02
DRN 7
Sector 5
tess_sector_05_drn07_v0
DRN 6
Sectors 1-3
tess_multisector_01_03_
DRN 5
Sector 4
tess_sector_04_drn05_
DRN 4
Sector 3
tess_sector_03_drn04
DRN 3
Sectors 1-2
tess_multisector_01_
DRN 2
Sector 2
tess_sector_02_drn
DRN 1
Sector 1
tess_sector_01_dr
NASA/TM—2019–220170
NASA
TESS Data Release Notes:
Sector 7, DR9
Michael M. Fausnaugh, Christopher J. Burke
Kavli Institute for Astrophysics and Space Science, Massachusetts Institute of
Cambridge, Massachusetts
Douglas A. Caldwell
SETI Institute, Mountain View, Calif
Jon M. Jenkins
Ames

The spacecraft was pointing at RA (J2000): 110.2559°; Dec (J2000): −32.6344°; Roll: 166.4476°. Two-minute cadence data were collected for 20,000 targets, and full frame images were collected every 30 minutes. See the TESS project Sector 7 observation page[3] for the coordinates of the spacecraft pointing and center field-of-view of each camera, as well as the detailed target list. Fields-of-view for each camera with all two-minute targets can be found at the TESS Guest Investigator Office observations status page[4].

1.1 Notes on Individual Targets

Five very bright stars (Tmag $\lesssim 2$) with large pixel stamps were not processed in the photometric pipeline. Target pixel files with raw data are provided, but no light curves were produced. The affected TIC IDs are 322899250, 64602863, 255559489, 38877693, 280310048.

Three stars (110798661, 300015238, and 354825493) had very bright stars nearby (110798652, 300015239 and 354825513 respectively). The contaminating flux for these objects is very large, and the pipeline assigns them disjoint photometric apertures that likely cause uncorrected systematic errors in the light curves.

Four targets (80466973, 124751941, 156934909, and 269407223) had apertures selected (25x25 pixels) that did not fully capture the bleed trails.

1.2 Spacecraft Pointing and Momentum dumps

The reaction wheel speeds were reset with momentum dumps every 3.125 days. FFIs taken during these times are marked with bit 6 (Reaction Wheel Desaturation Events) set. Only one or two FFIs are affected by each momentum dump. Figure 1 summarizes the pointing performance over the course of the sector based on Fine Pointing telemetry.

[3] https://tess.mit.edu/observations/sector-7

[4] https://heasarc.gsfc.nasa.gov/docs/tess/status.html

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SPOC Architecture:

Jenkins et al. 2016

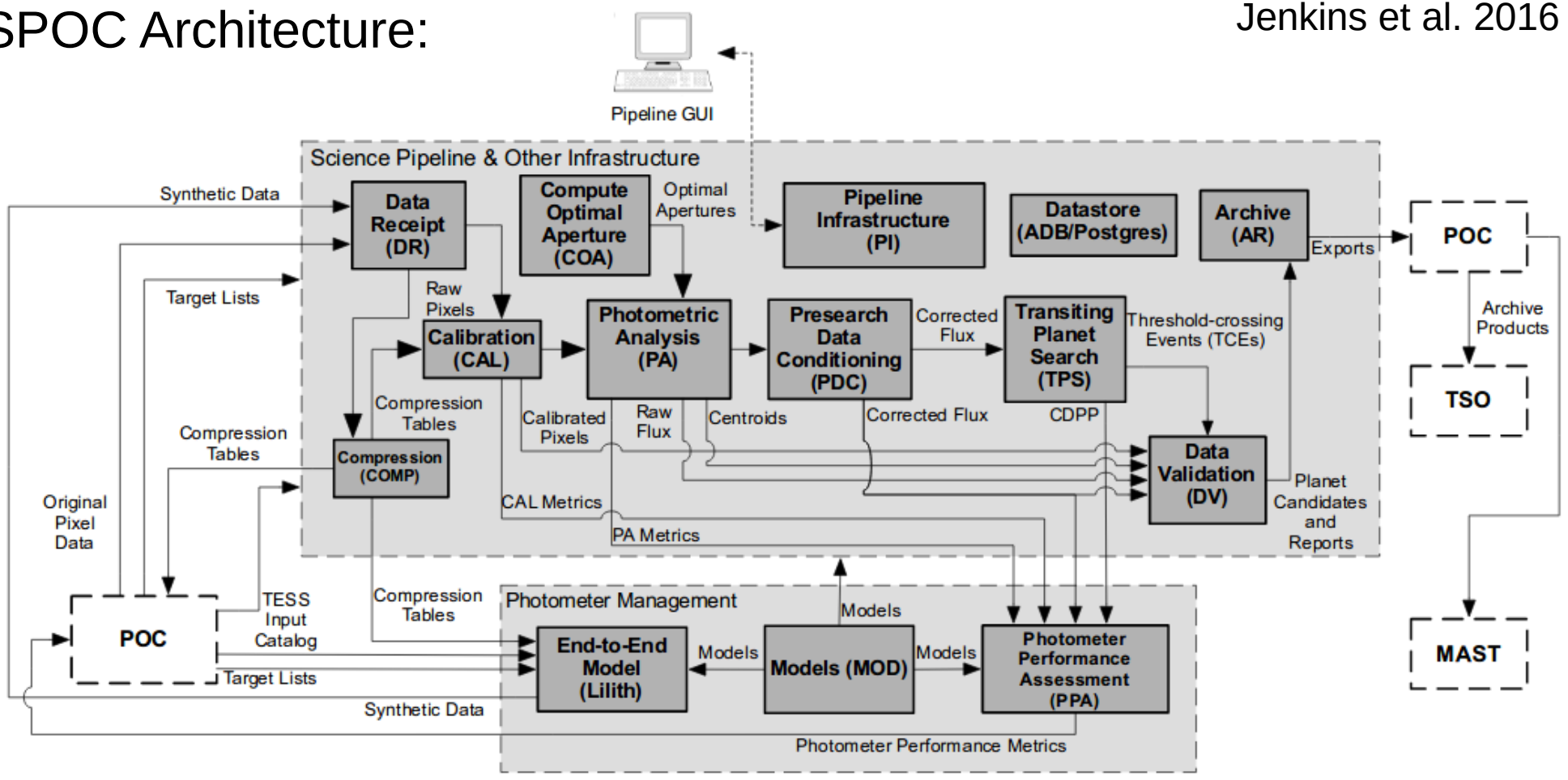
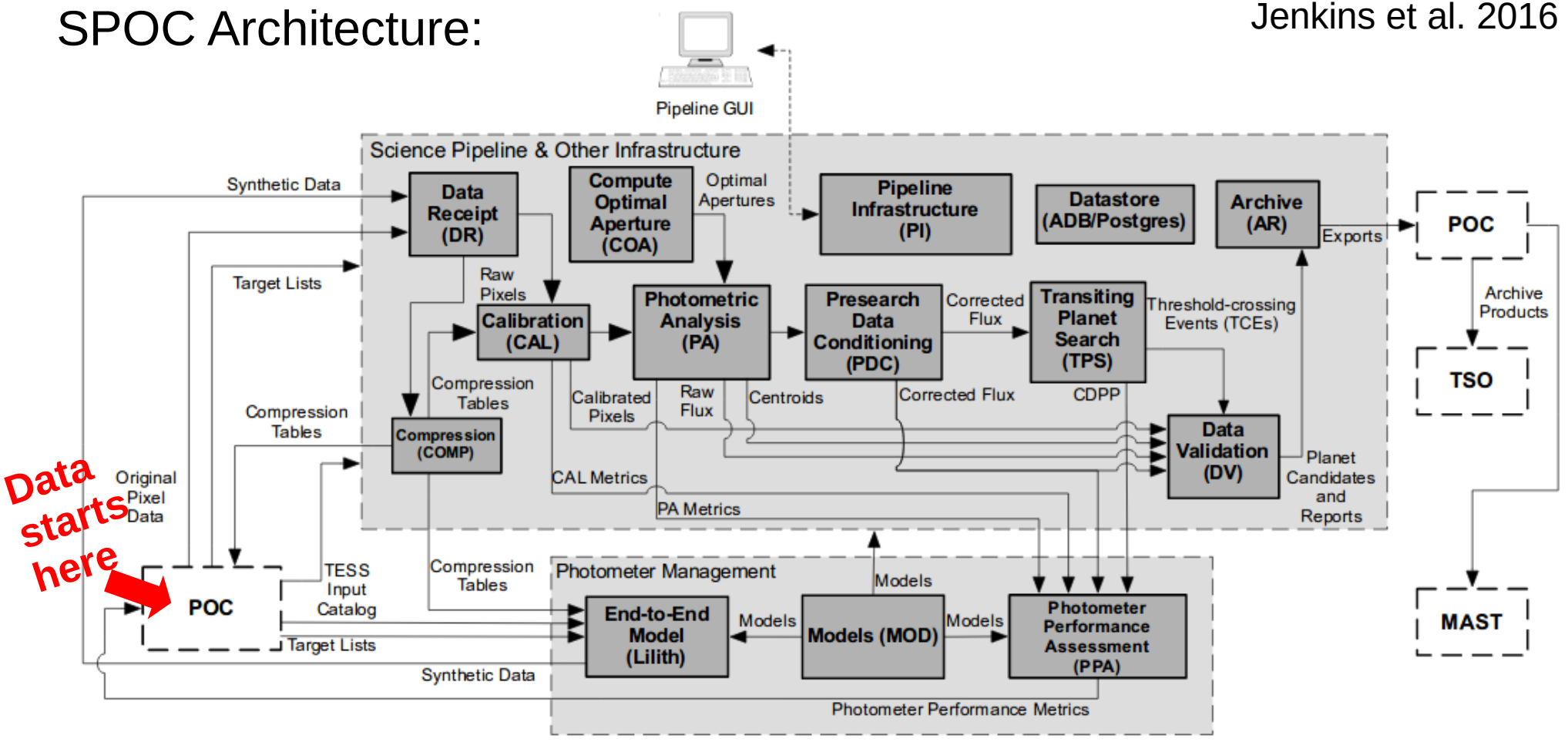


Figure 3. Architecture diagram of the TESS Science Processing Operations Center indicating the 14 major components comprising the TESS science pipeline and photometer management functions.

SPOC Architecture:

Jenkins et al. 2016



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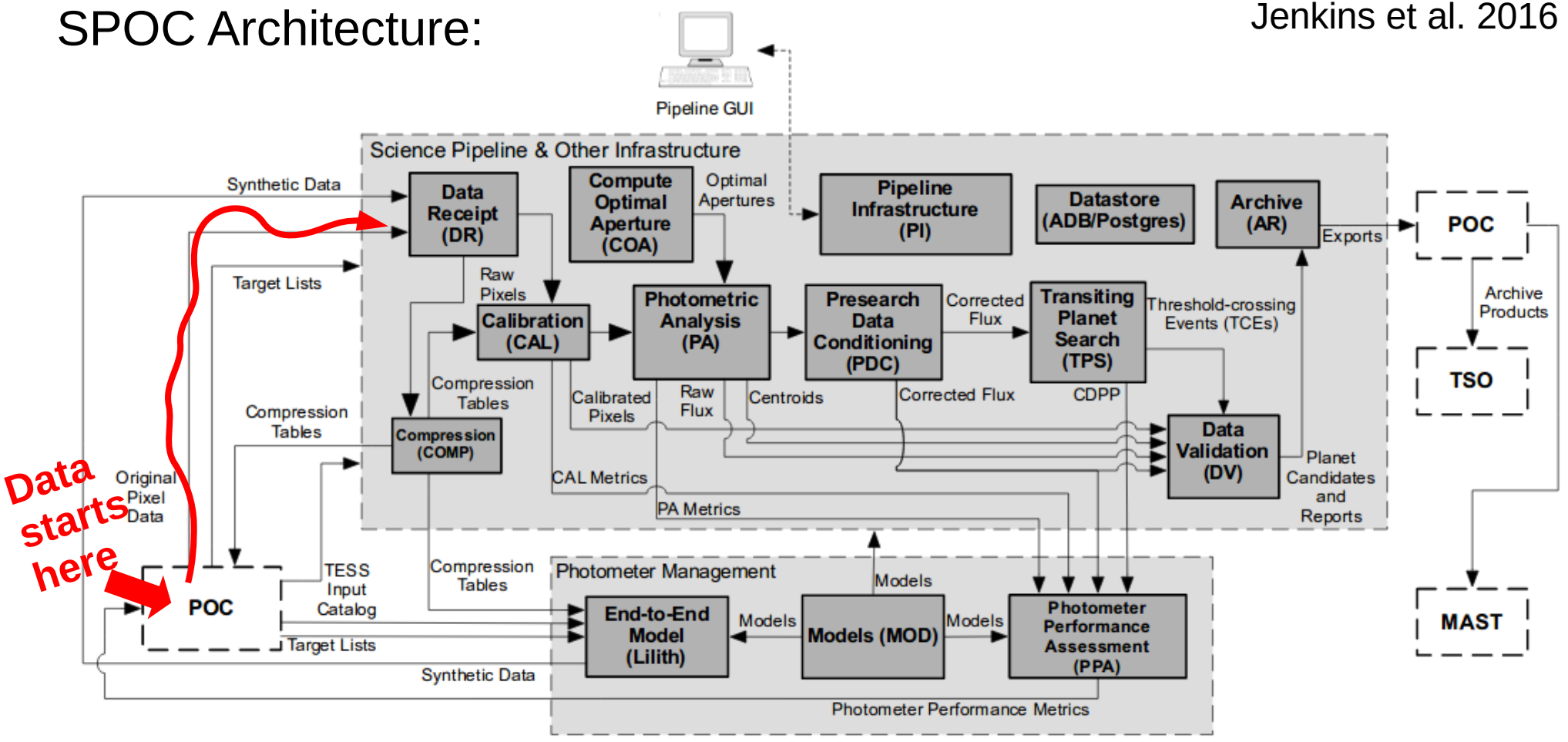

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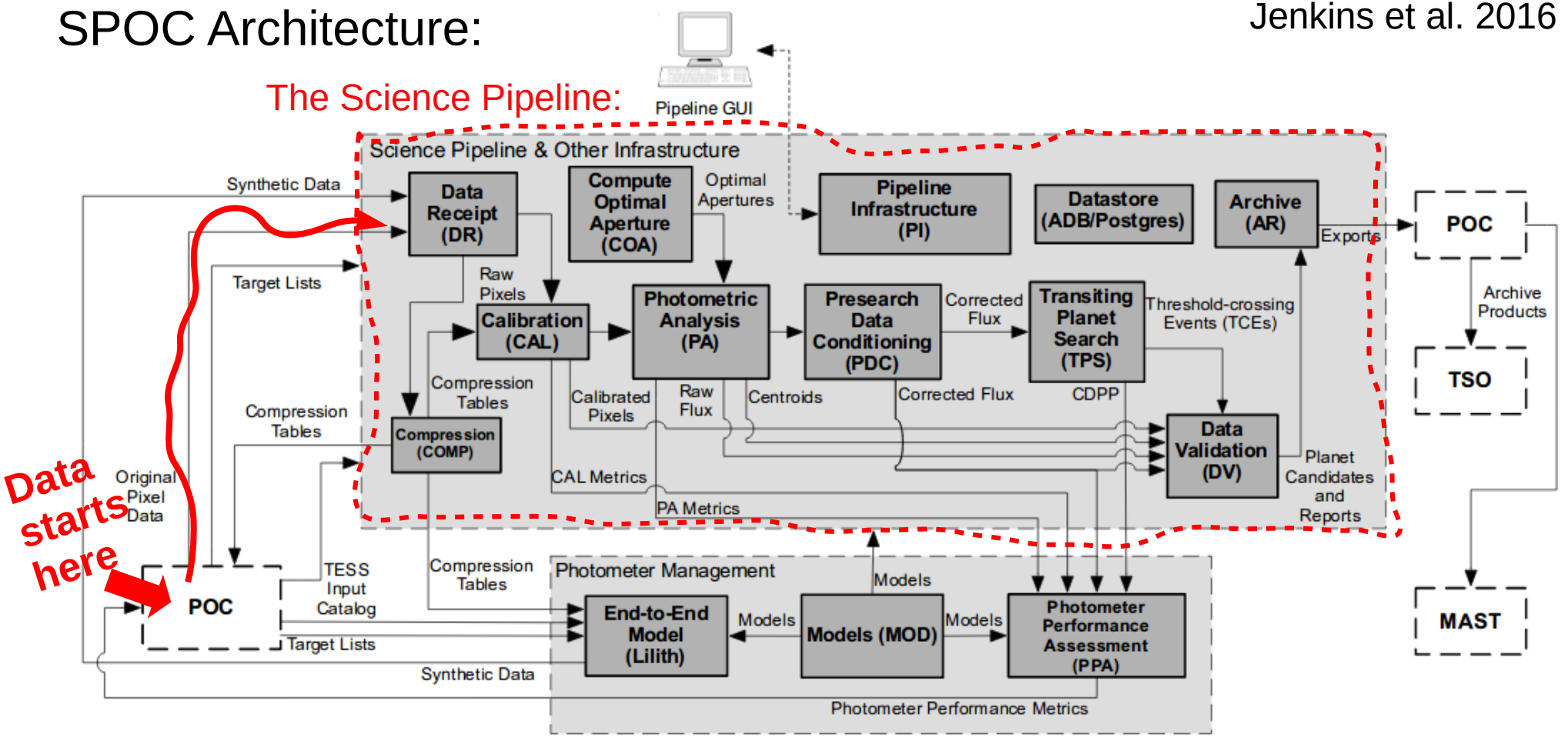

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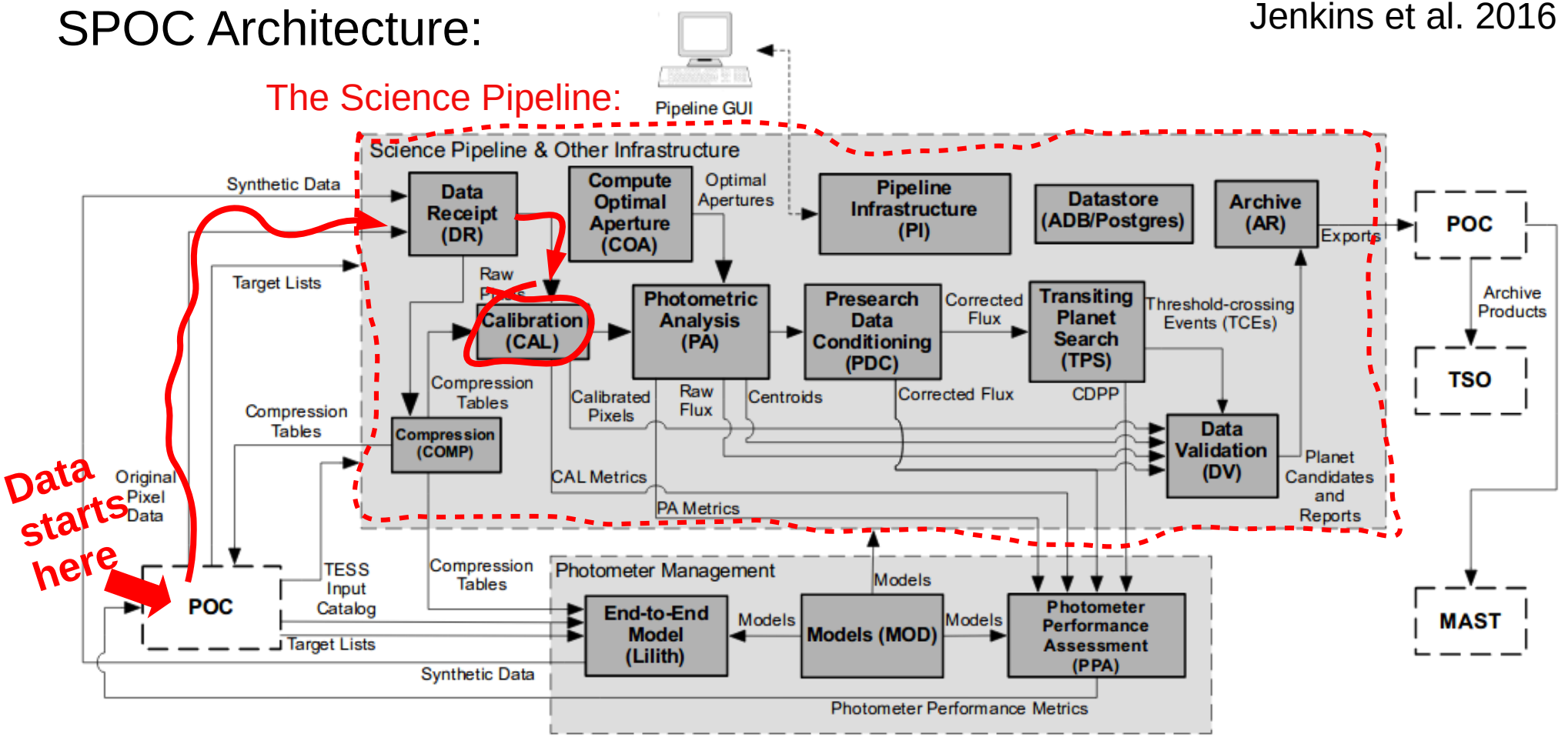

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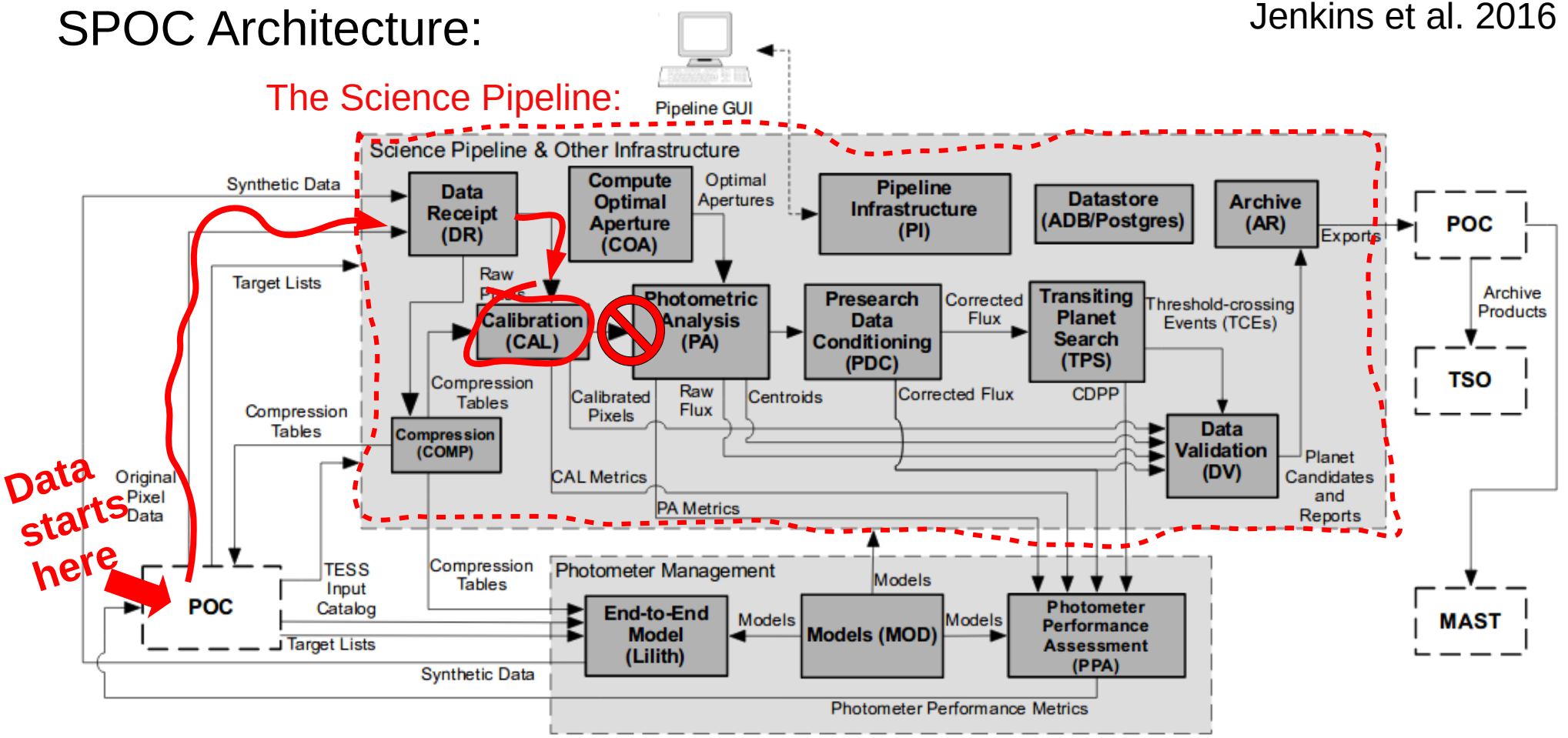

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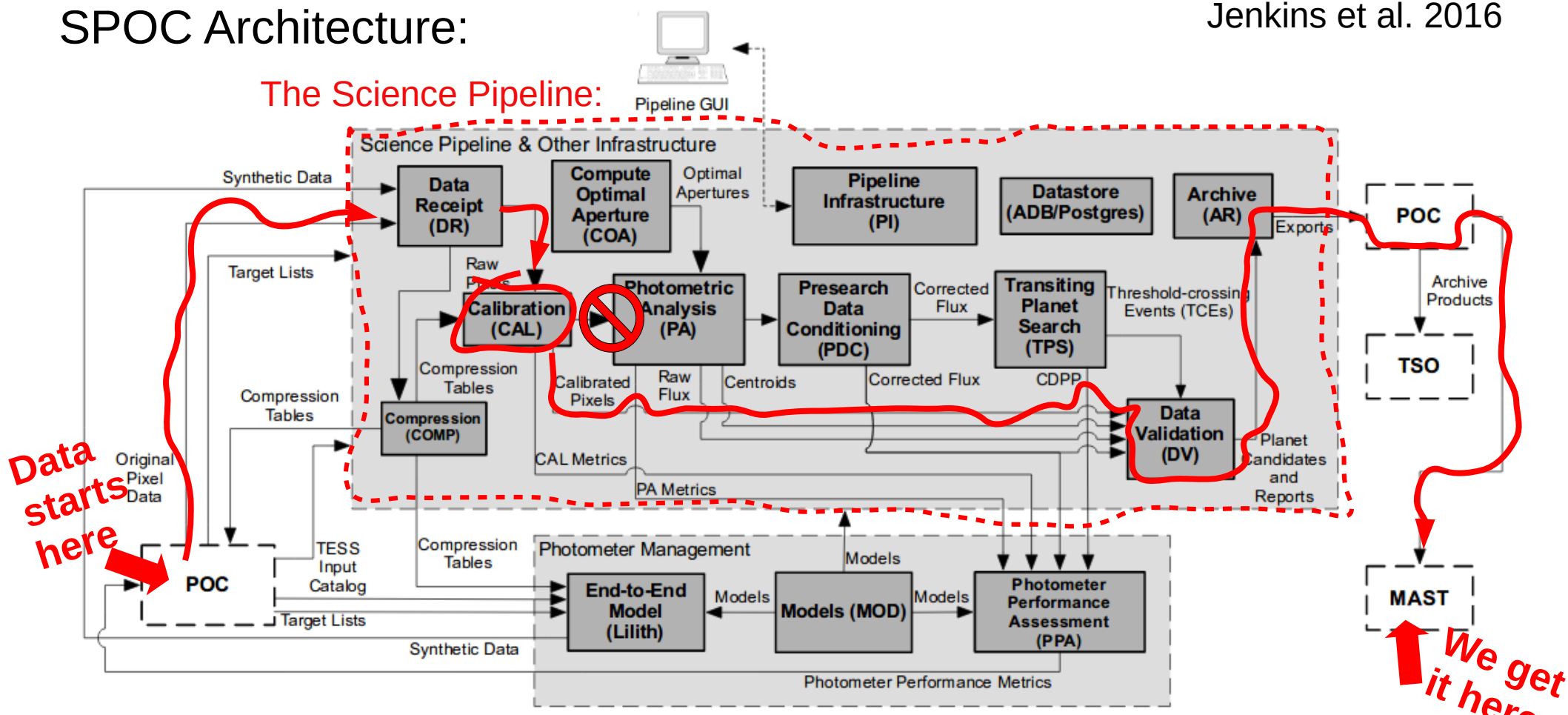
Jenkins et al. 2016

The Science Pipeline:



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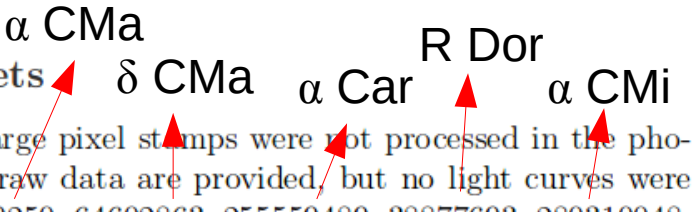

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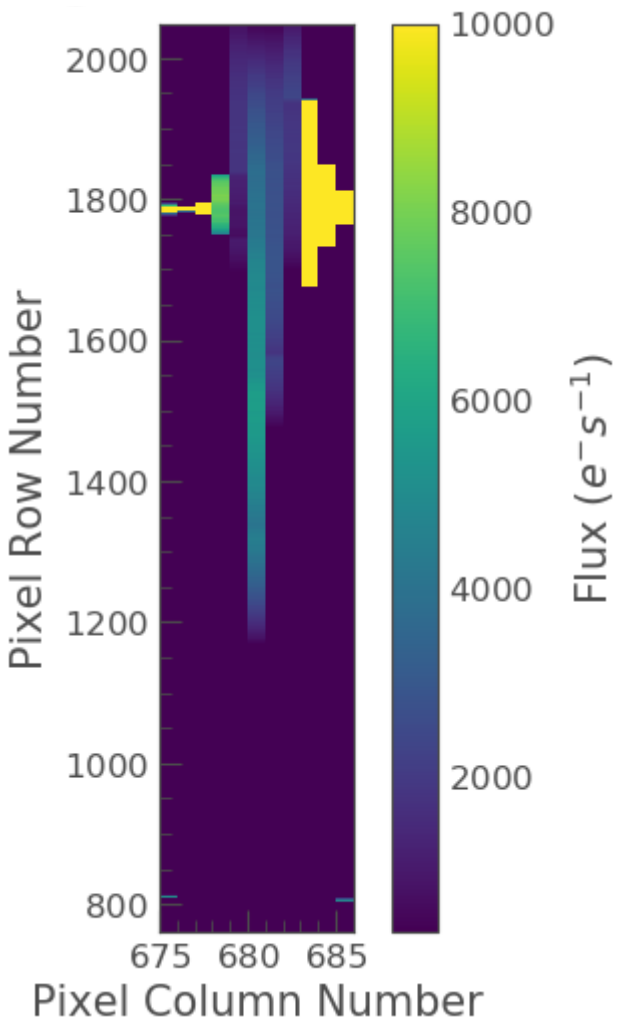
[3] https://tess.mit.edu/observations/sector-7
[4] https://heasarc.gsfc.nasa.gov/docs/tess/status.html

α Canis Majoris

TIC 322899250

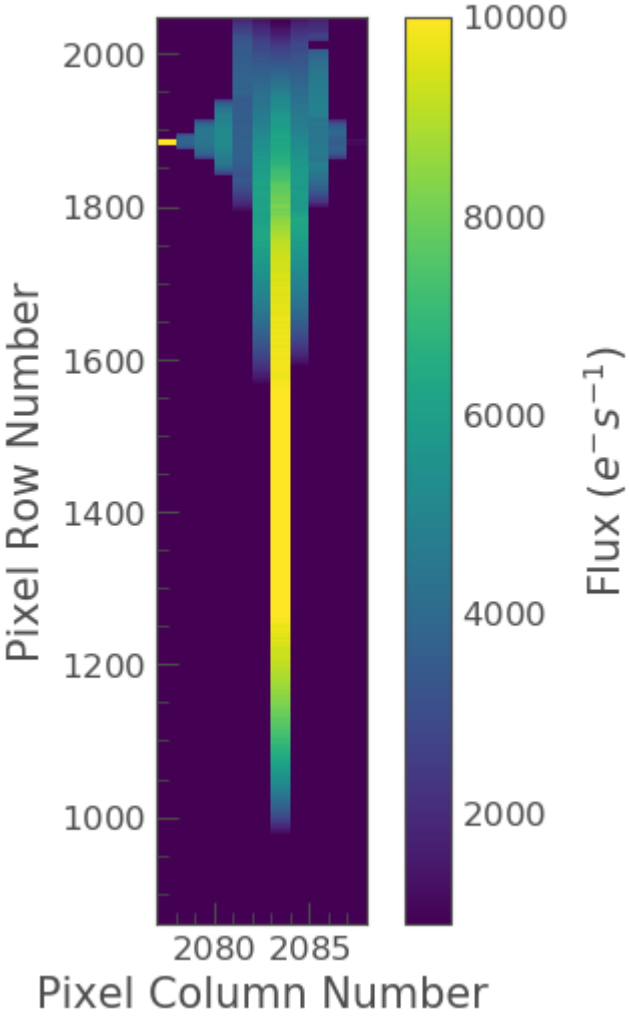
Tmag = -0.891

A1V + DA



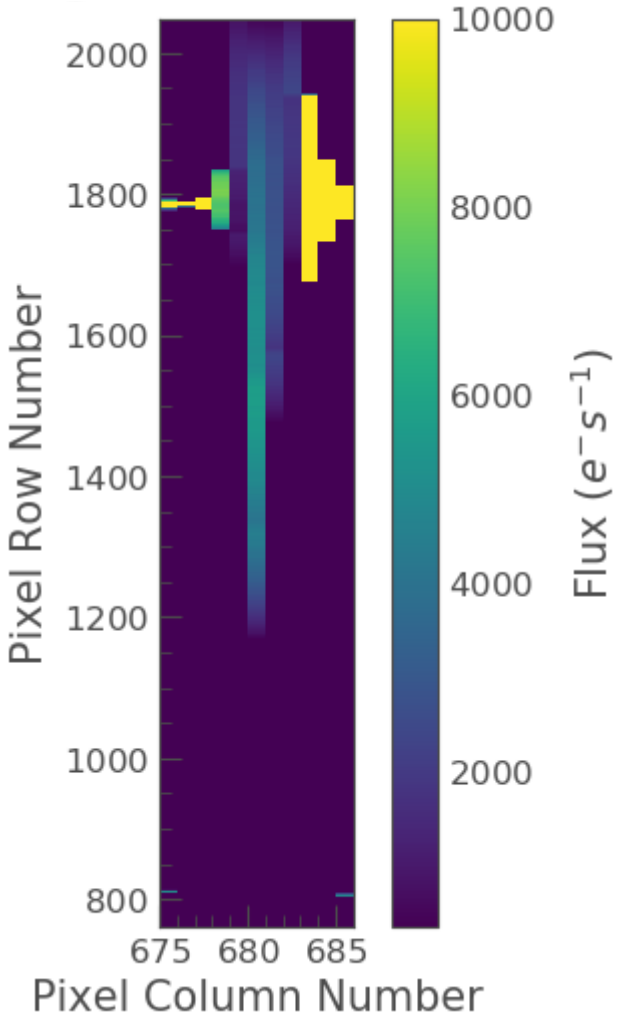
Sector 6

Sector 7



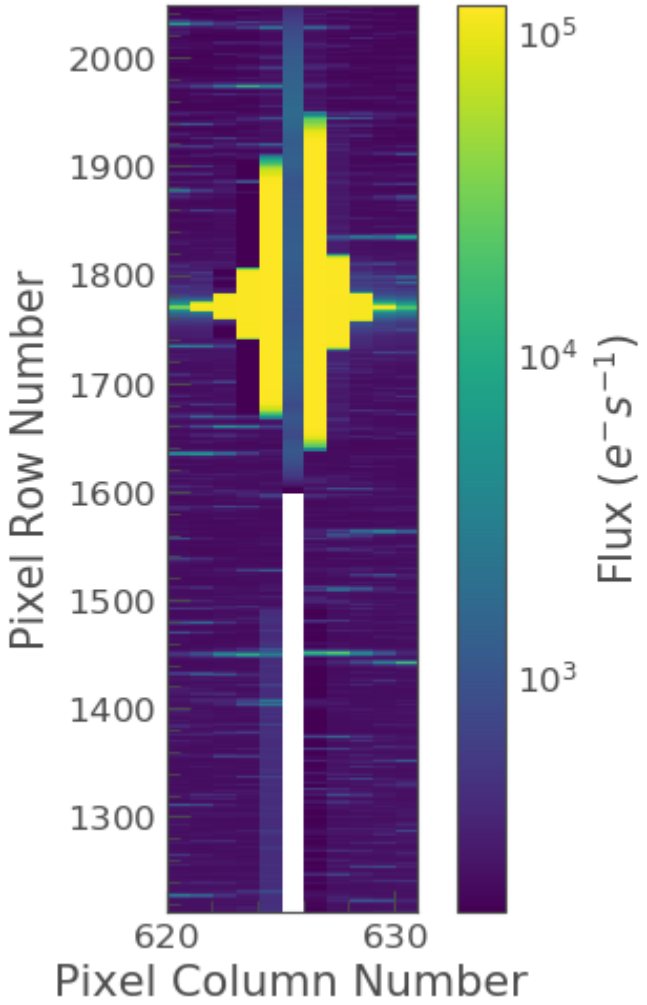
α Canis Majoris

TIC 322899250



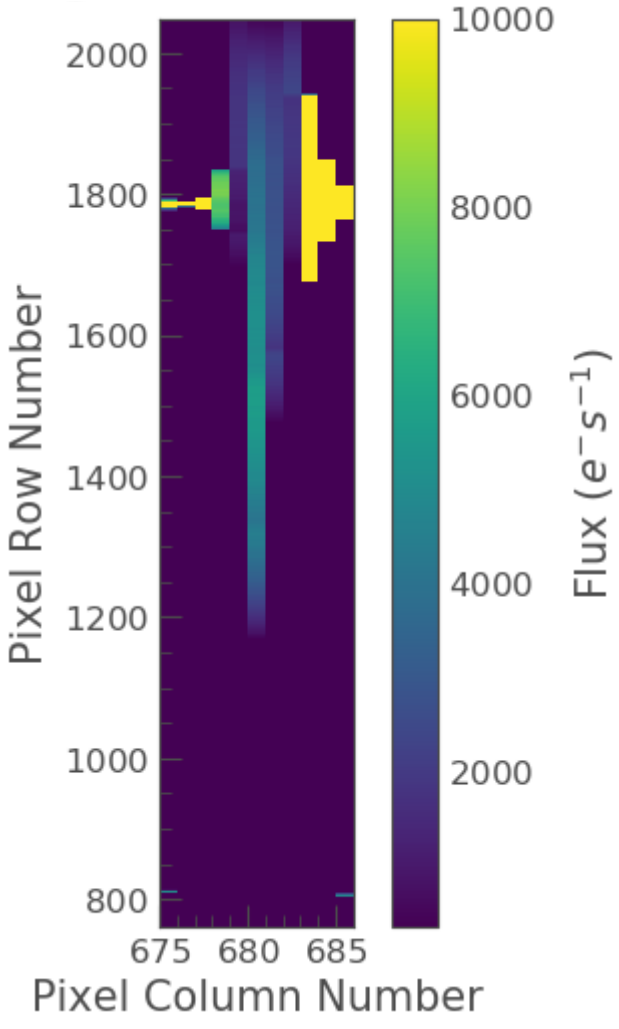
α Canis Minoris

TIC 280310048



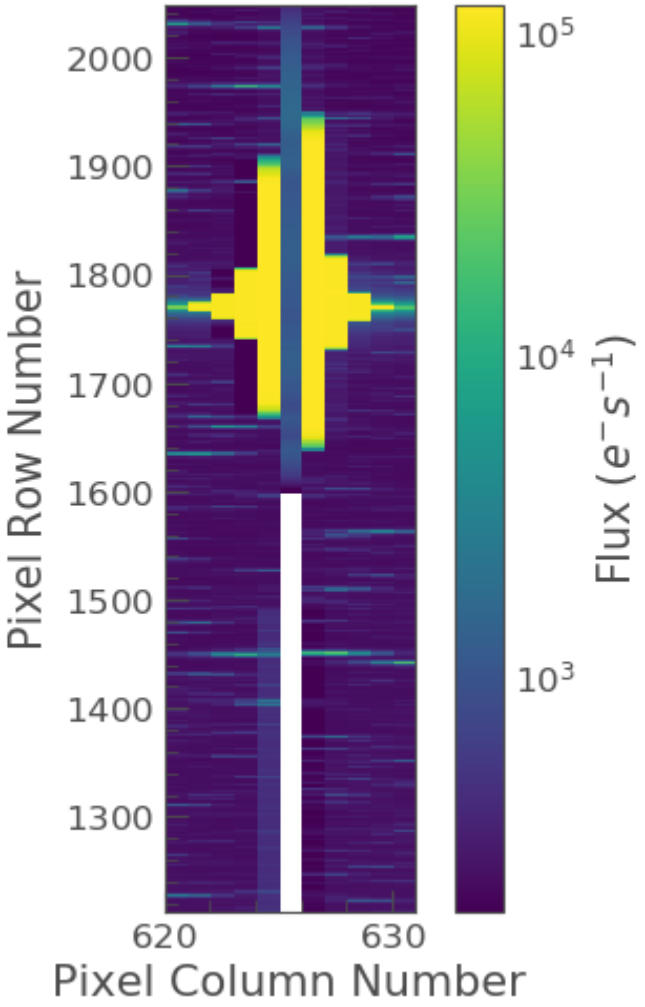
α Canis Majoris

TIC 322899250



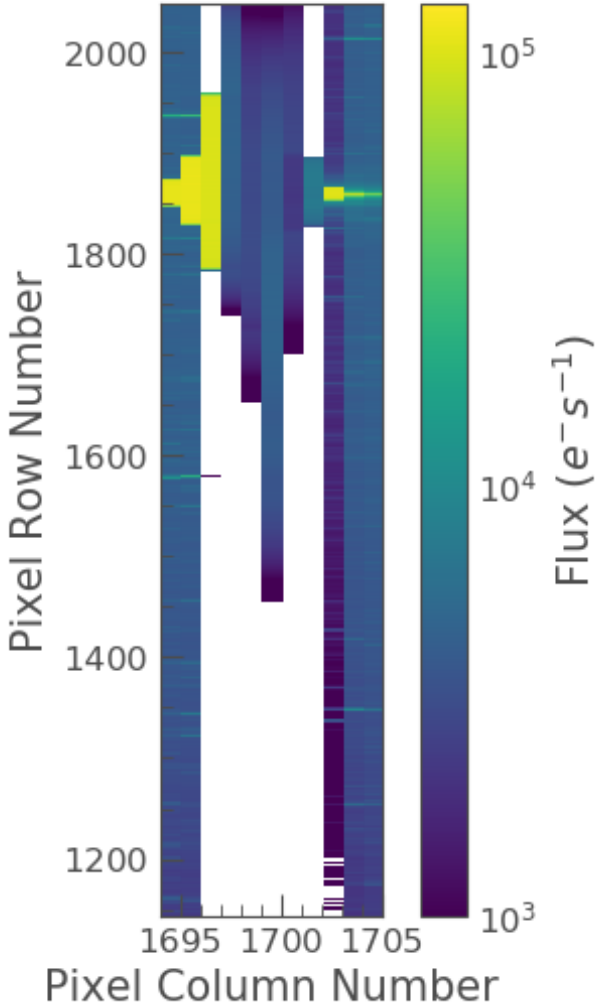
α Canis Minoris

TIC 280310048



α Centauri

TIC 399646462



appear. This figure can be used to identify periods affected by scattered light and the relative contributions of the Earth and Moon to the background. However, the background intensity and locations of scattered light features depend on additional factors, such as the Earth/Moon azimuth and distance from the spacecraft.

3 Anomalous Effects

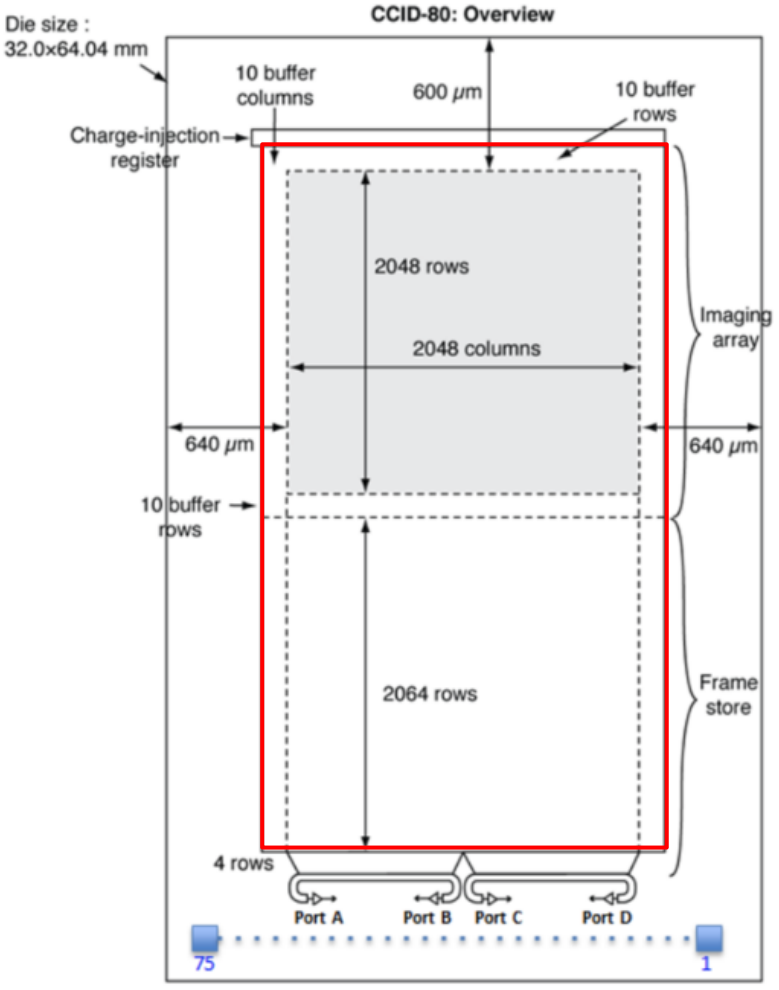
3.1 Smear Correction Issues

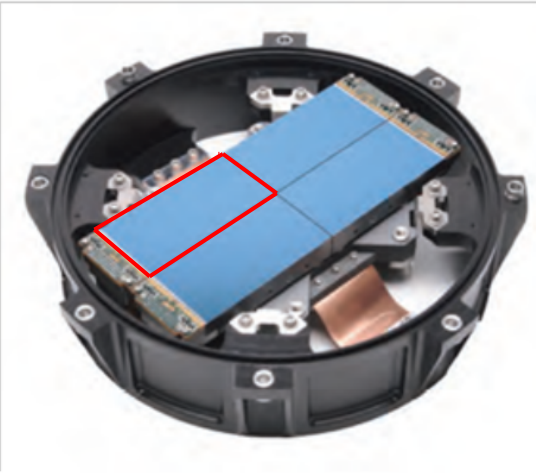
The following columns were impacted by bright stars in the science frame and/or the upper buffer rows, which bleed into the upper serial register resulting in an overestimated smear correction.

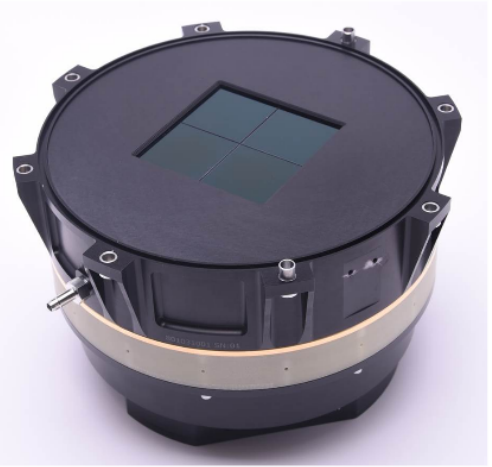
- Camera 1, CCD 4, Columns 623-626, Star Procyon A
- Camera 2, CCD 4, Columns 2068-2092, Star Sirius A

3.2 Black Level Residuals

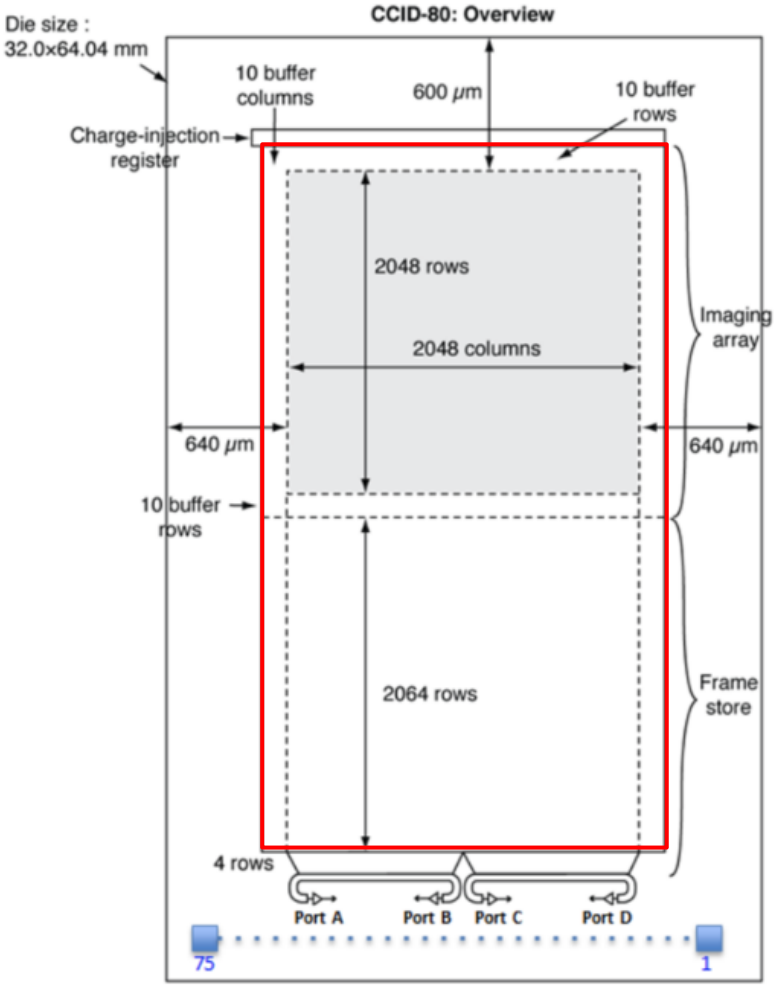
The Sector 7 data from some channels show a small non-zero residual in the mean black level after calibration that is either static (e.g., camera 3, CCD 2, output D) or slowly time varying (e.g., camera 4, CCD 1, all outputs and camera 4, CCD 3, all outputs). The level of

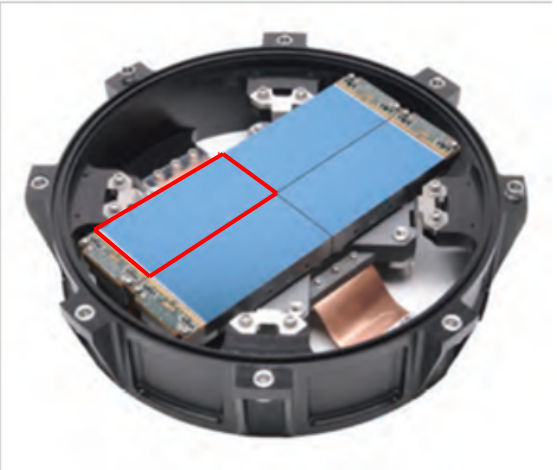


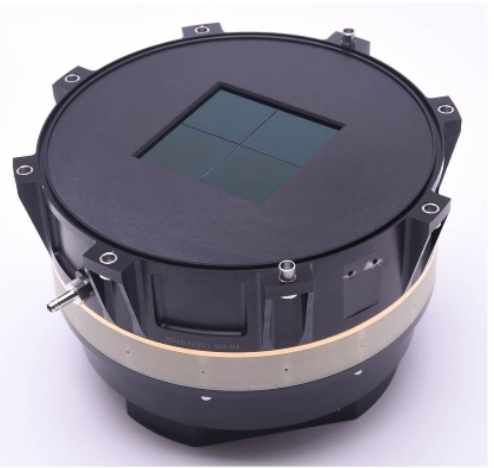




Figures from TESS Instrument Handbook

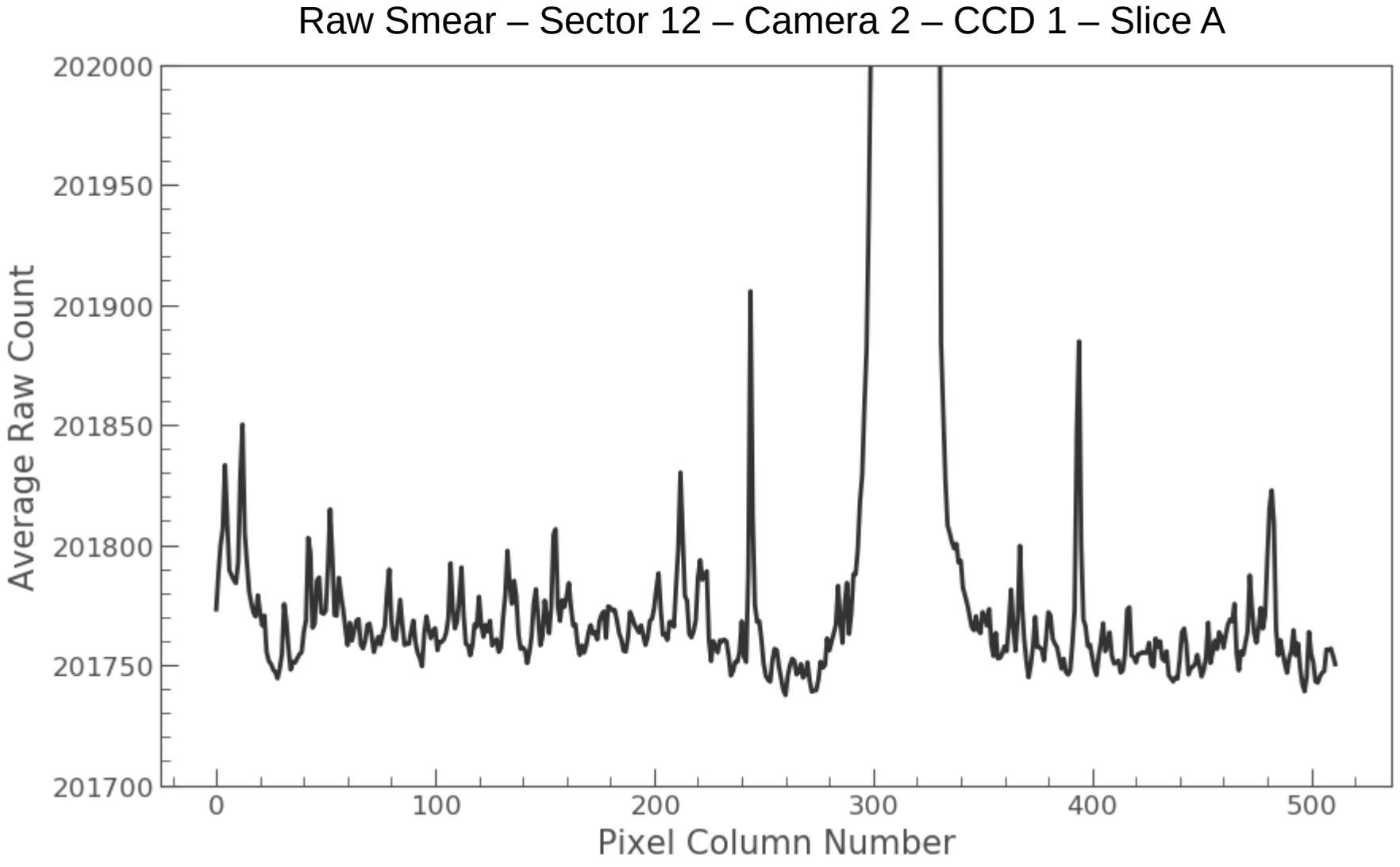


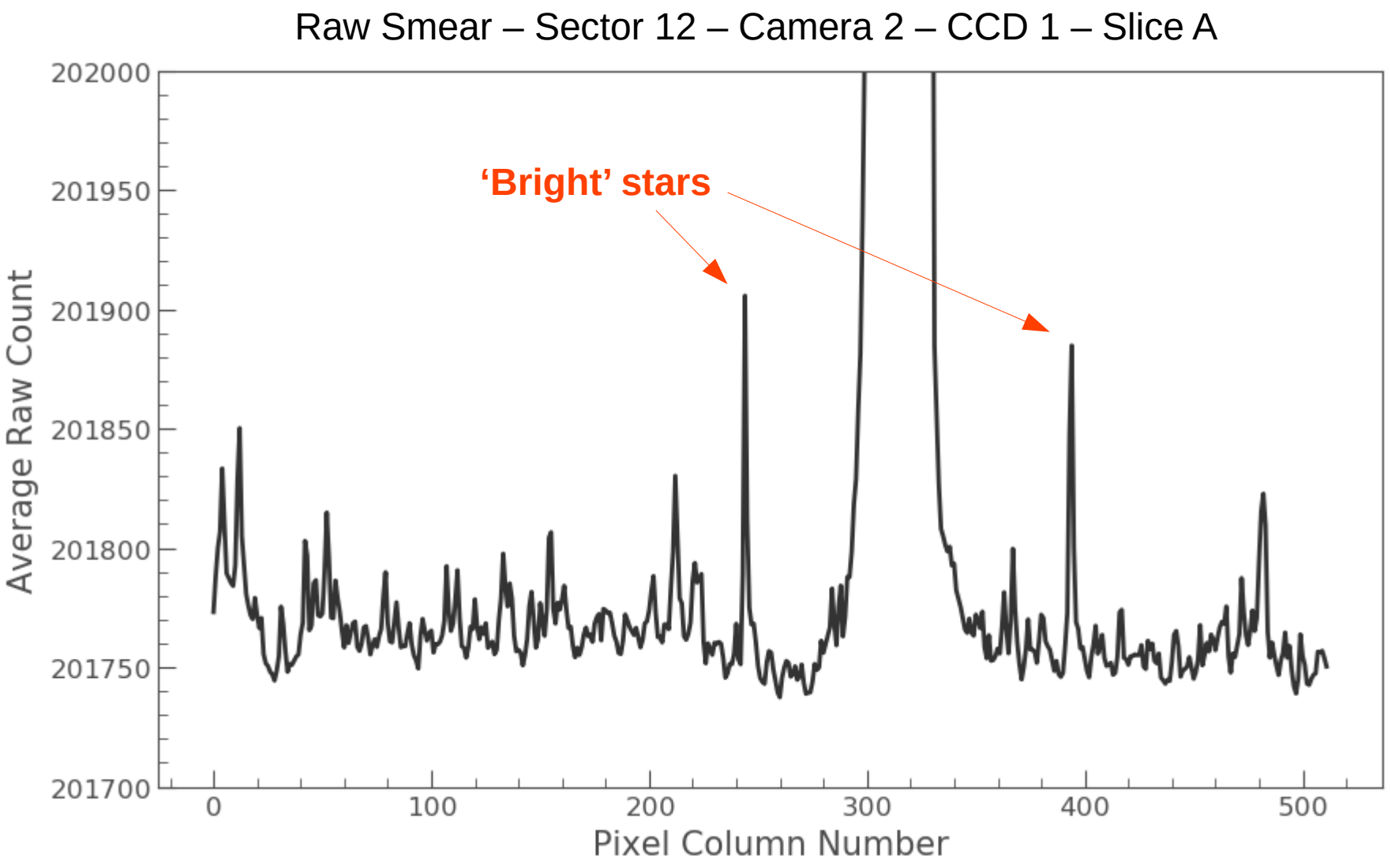


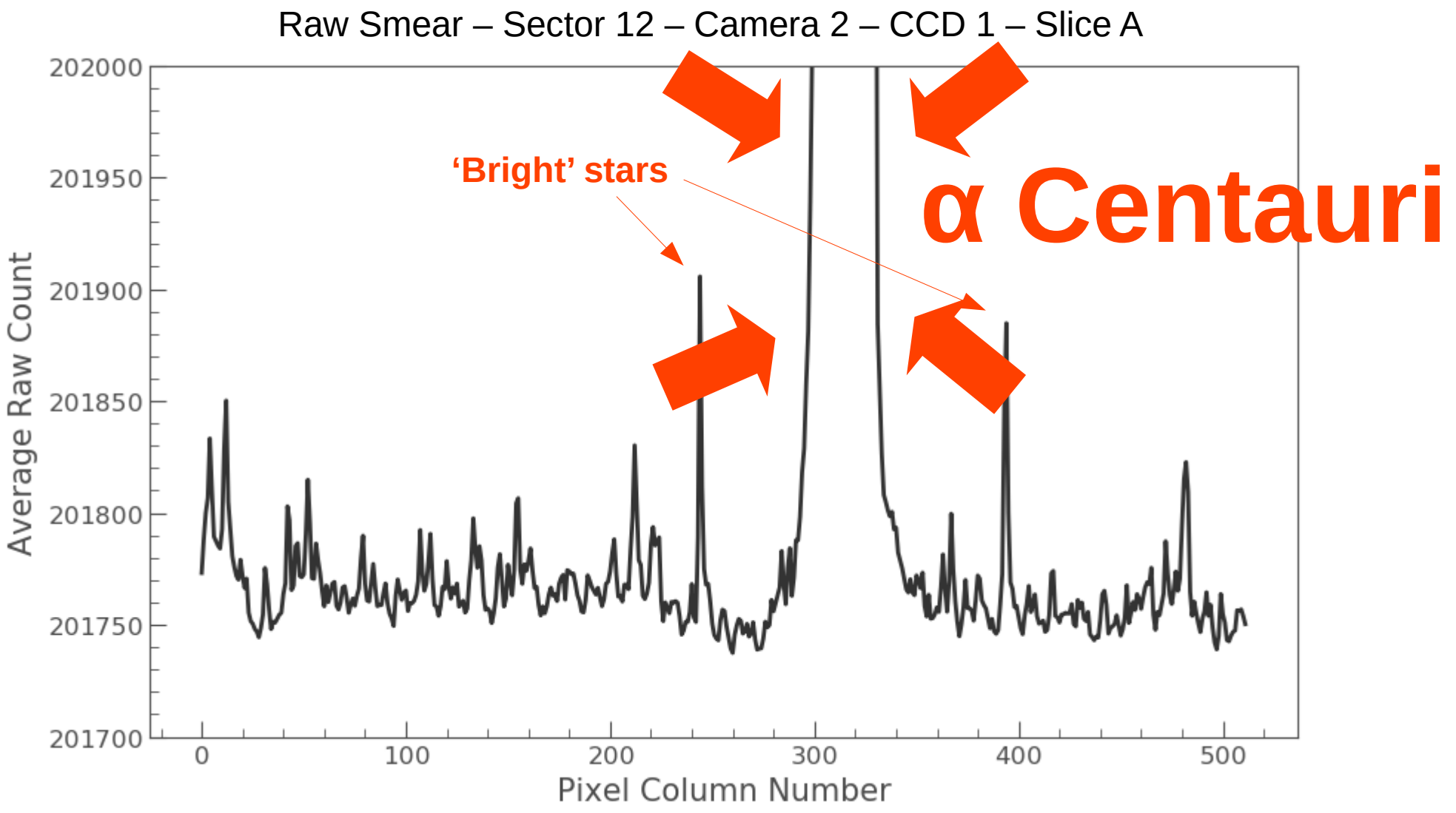


				Slice A	Slice B	Slice C	Slice D				
A	B	C	D	10 Virtual Rows	10 Virtual Rows	10 Virtual Rows	10 Virtual Rows	A	B	C	D
				10 Smear Rows	10 Smear Rows	10 Smear Rows	10 Smear Rows				
				10 Buffer Rows	10 Buffer Rows	10 Buffer Rows	10 Buffer Rows				
11 Virtual Columns (Underclocks/Leading Black)	11 Virtual Columns (Underclocks/Leading Black)	11 Virtual Columns (Underclocks/Leading Black)	11 Virtual Columns (Underclocks/Leading Black)	Imaging Area: 512 Columns x 2048 Rows	Imaging Area: 512 Columns x 2048 Rows Columns Reversed (In Physical Order)	Imaging Area: 512 Columns x 2048 Rows	Imaging Area: 512 Columns x 2048 Rows Columns Reversed	11 Virtual Columns (Overclocks/Trailing Black)	11 Virtual Columns (Overclocks/Trailing Black)	11 Virtual Columns (Overclocks/Trailing Black)	11 Virtual Columns (Overclocks/Trailing Black)

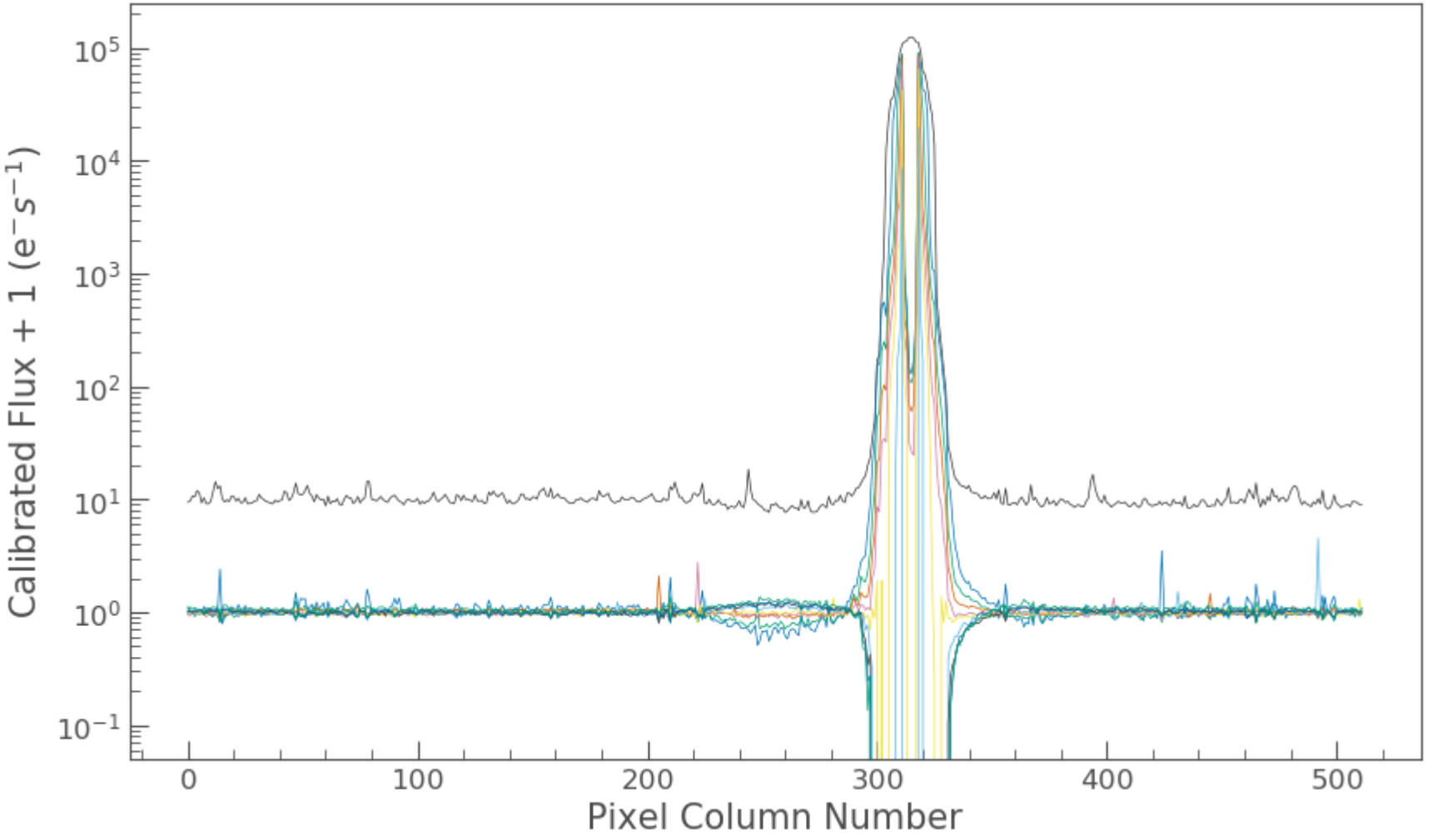
Figures from TESS Instrument Handbook


Raw Smear – Sector 12 – Camera 2 – CCD 1 – Slice A
202000
201950
201900
201850
201800
201750
201700
Average Raw Count
0
100
200
300
400
500
Pixel Column Number

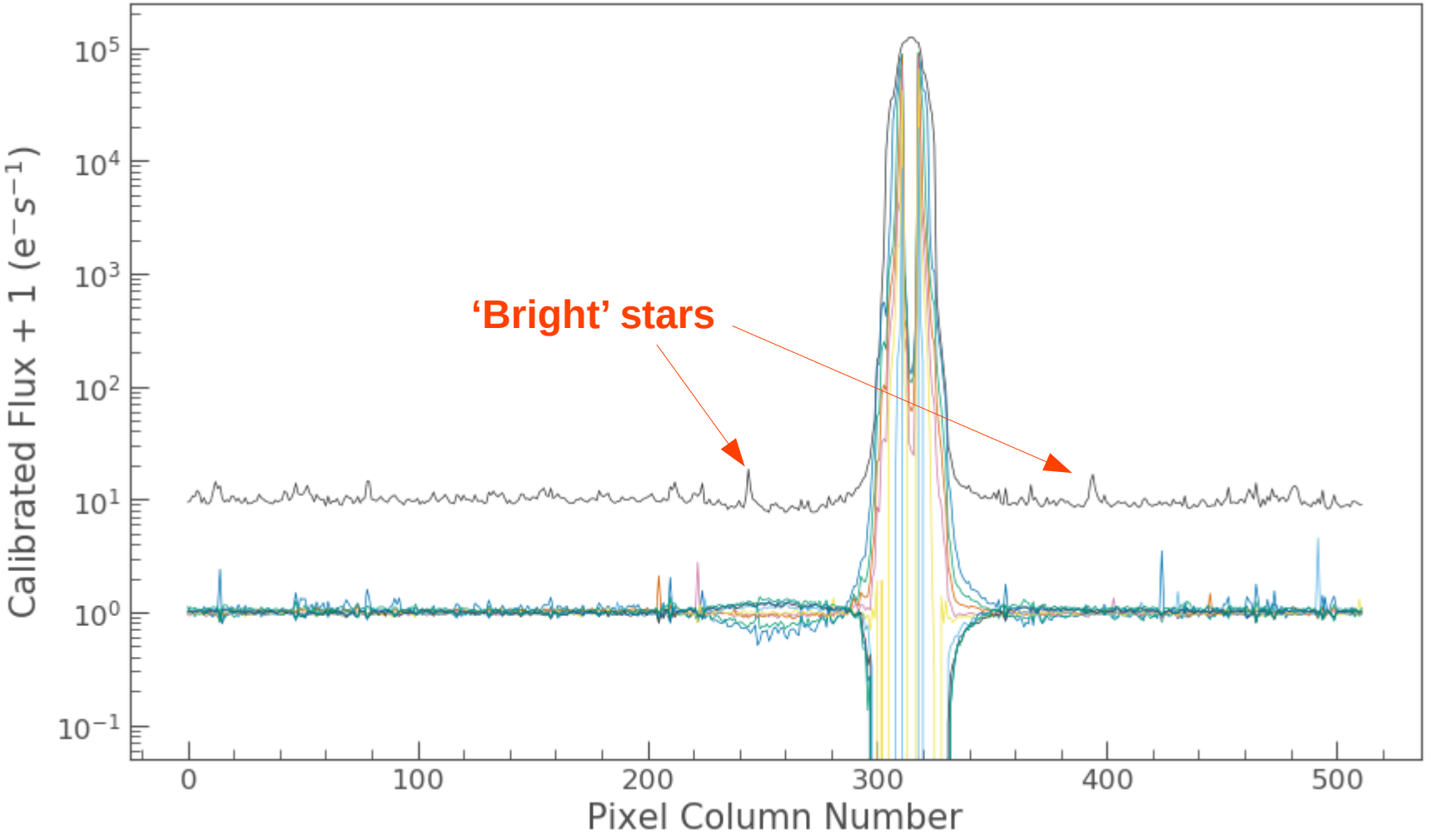

Raw Smear – Sector 12 – Camera 2 – CCD 1 – Slice A
‘Bright’ stars
Average Raw Count
202000
201950
201900
201850
201800
201750
201700
0
100
200
300
400
500
Pixel Column Number


Raw Smear – Sector 12 – Camera 2 – CCD 1 – Slice A
‘Bright’ stars
α Centauri
Average Raw Count
202000
201950
201900
201850
201800
201750
201700
0
100
200
300
400
500
Pixel Column Number

Calibrated Smear – Sector 12 – Camera 2 – CCD 1 – Slice A

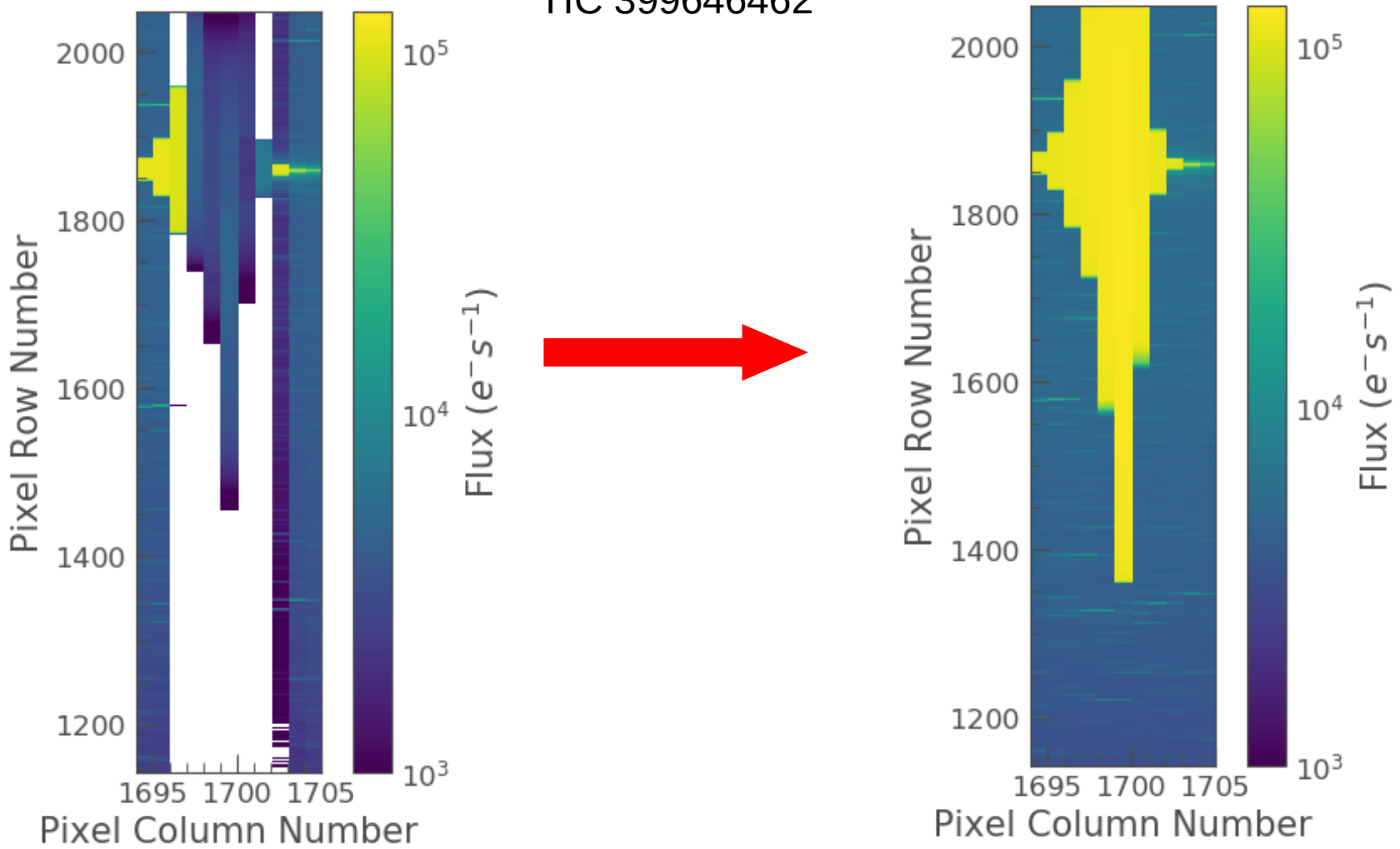


Calibrated Smear – Sector 12 – Camera 2 – CCD 1 – Slice A

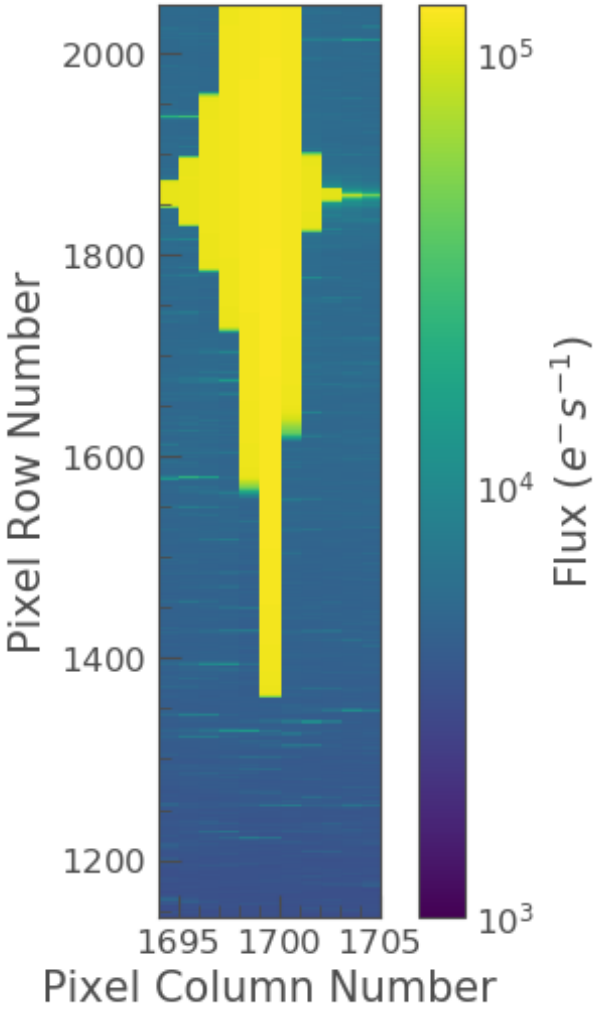


α Centauri

TIC 399646462

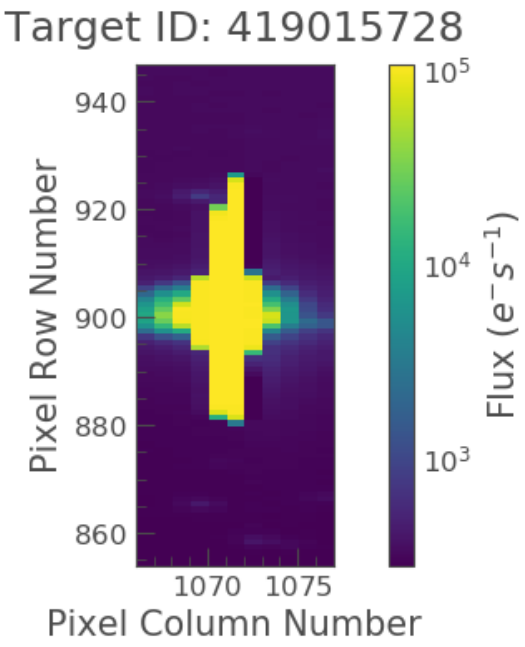


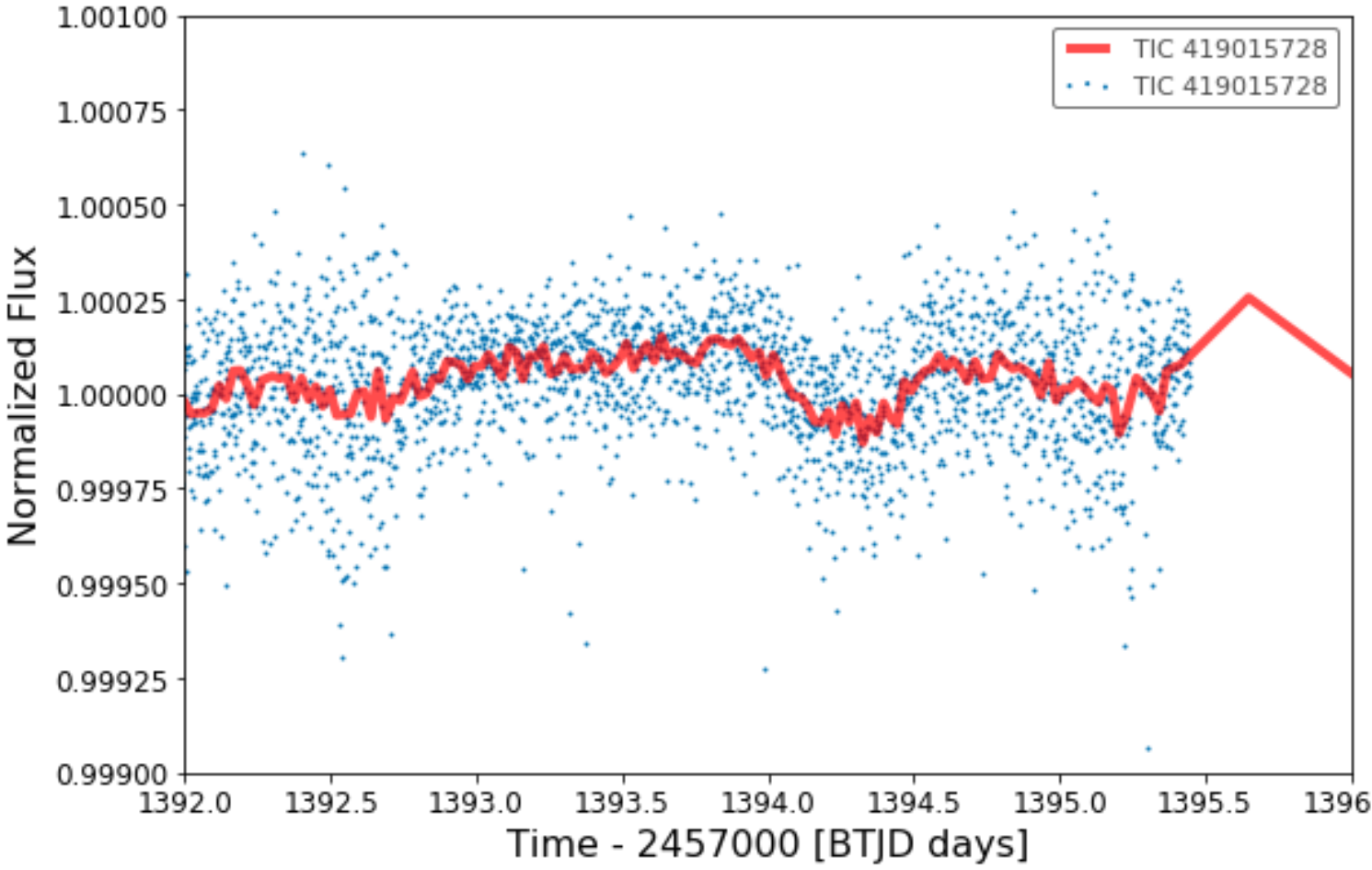
Backgrounds



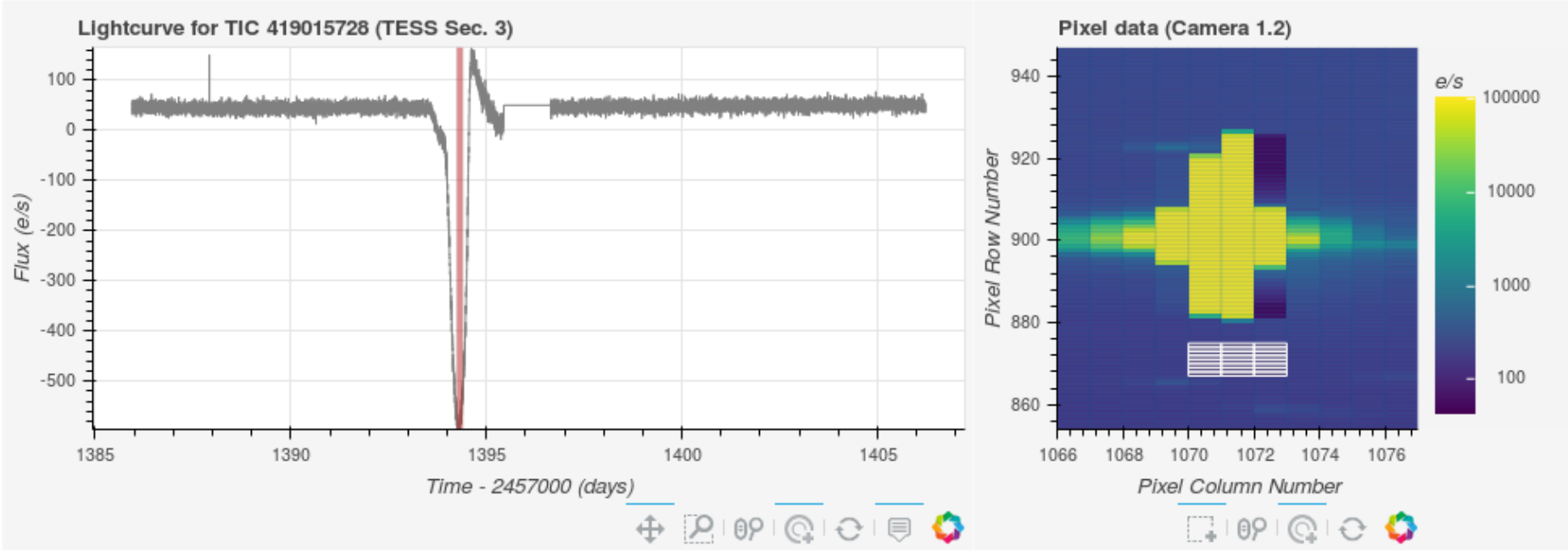
τ Ceti

Nora Eisner's talk yesterday on Planet Hunters TESS





In [7]:
```
tpf3.interact()
```

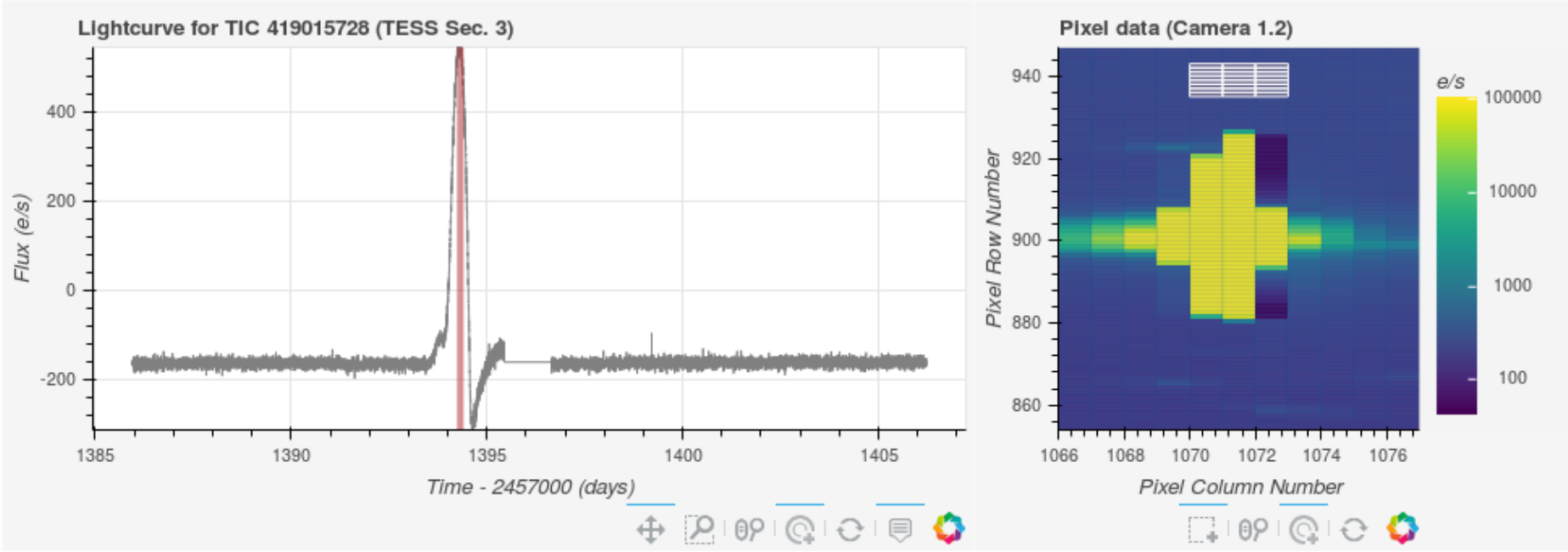


Cadence Number: **120140**

Screen Stretch (log): **1.64 .. 5.02**

Save Lightcurve

In [7]:
```
tpf3.interact()
```



Cadence Number: **120140**

Screen Stretch (log): **1.64 .. 5.02**

Save Lightcurve

TASOC FFI backgrounds

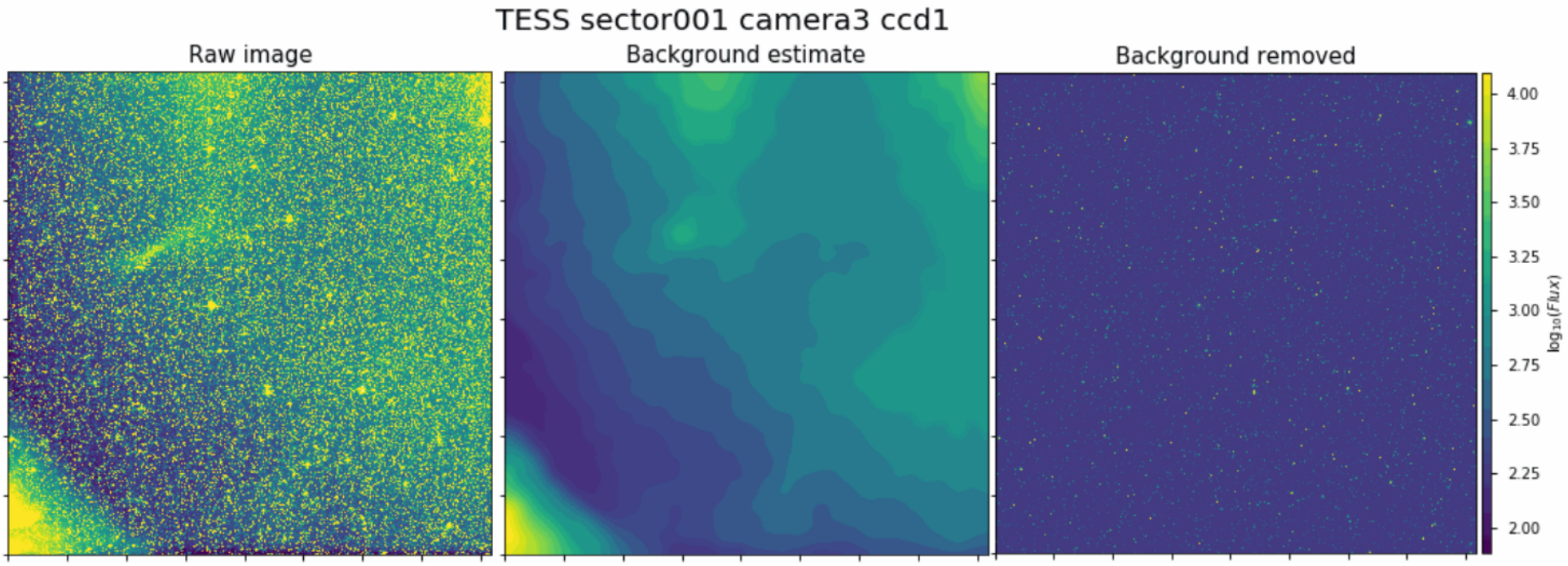


Image credit: Oliver Hall

TASOC FFI backgrounds

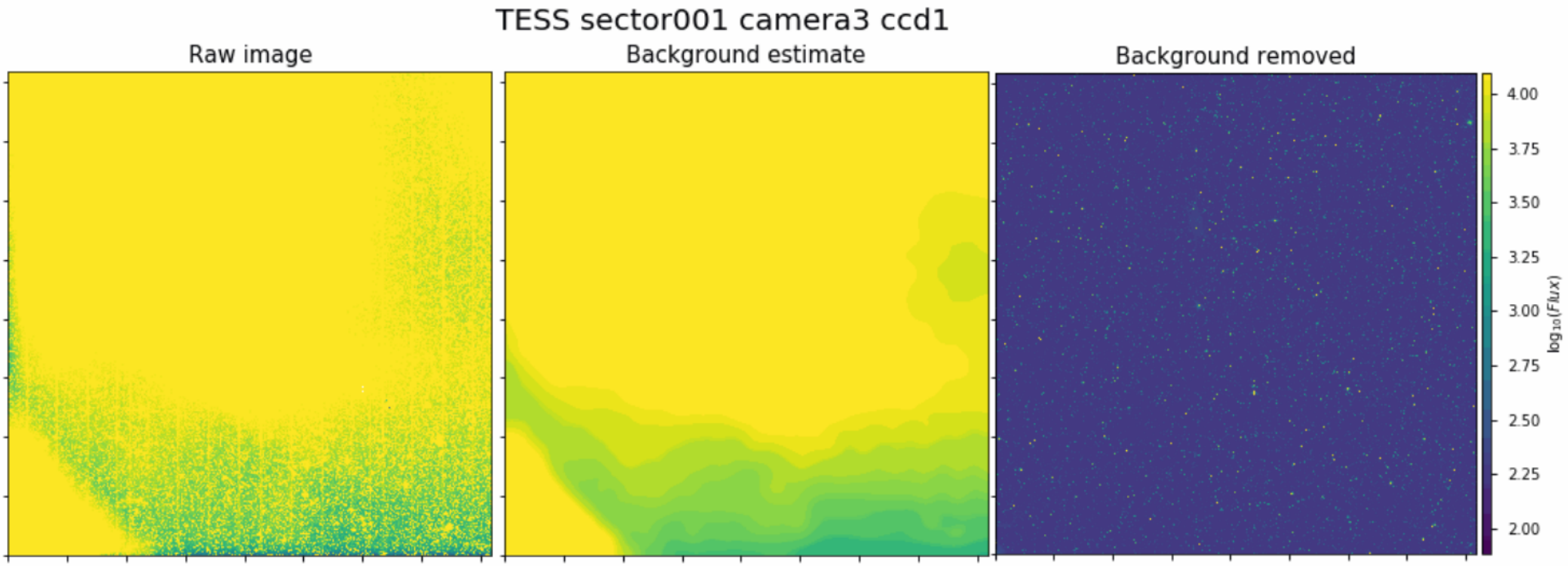


Image credit: Oliver Hall

TASOC FFI backgrounds

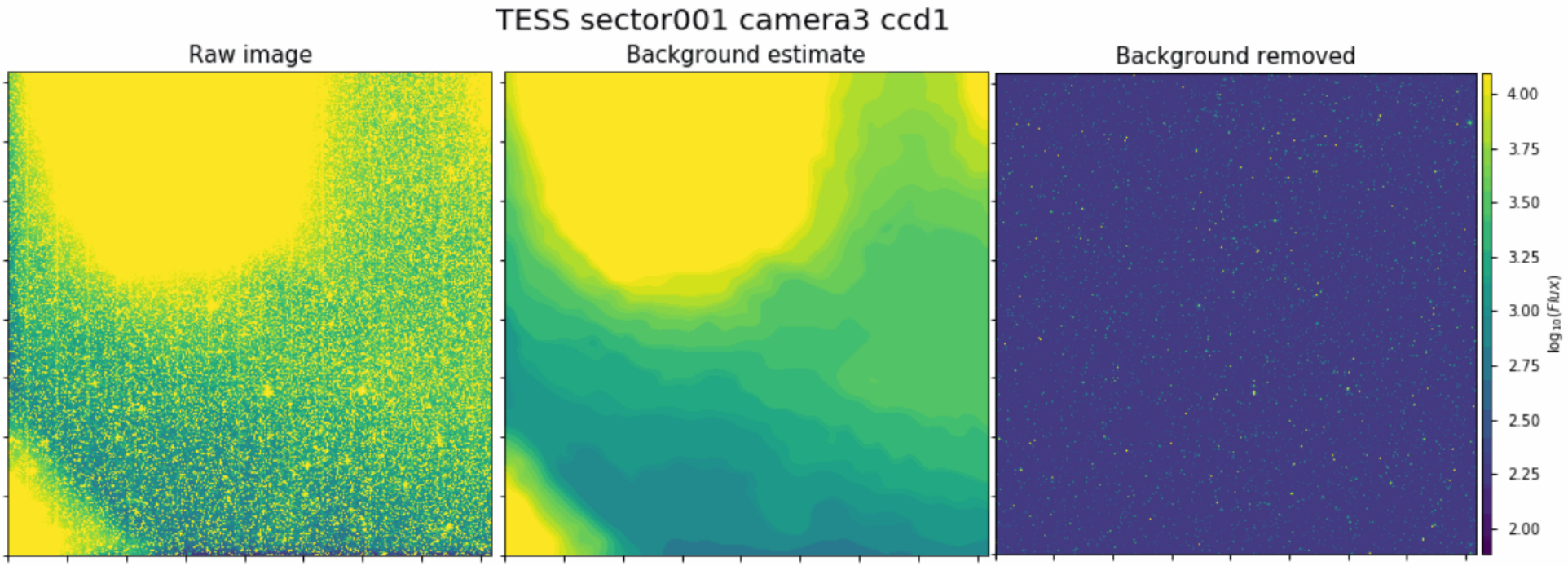


Image credit: Oliver Hall

TASOC FFI backgrounds

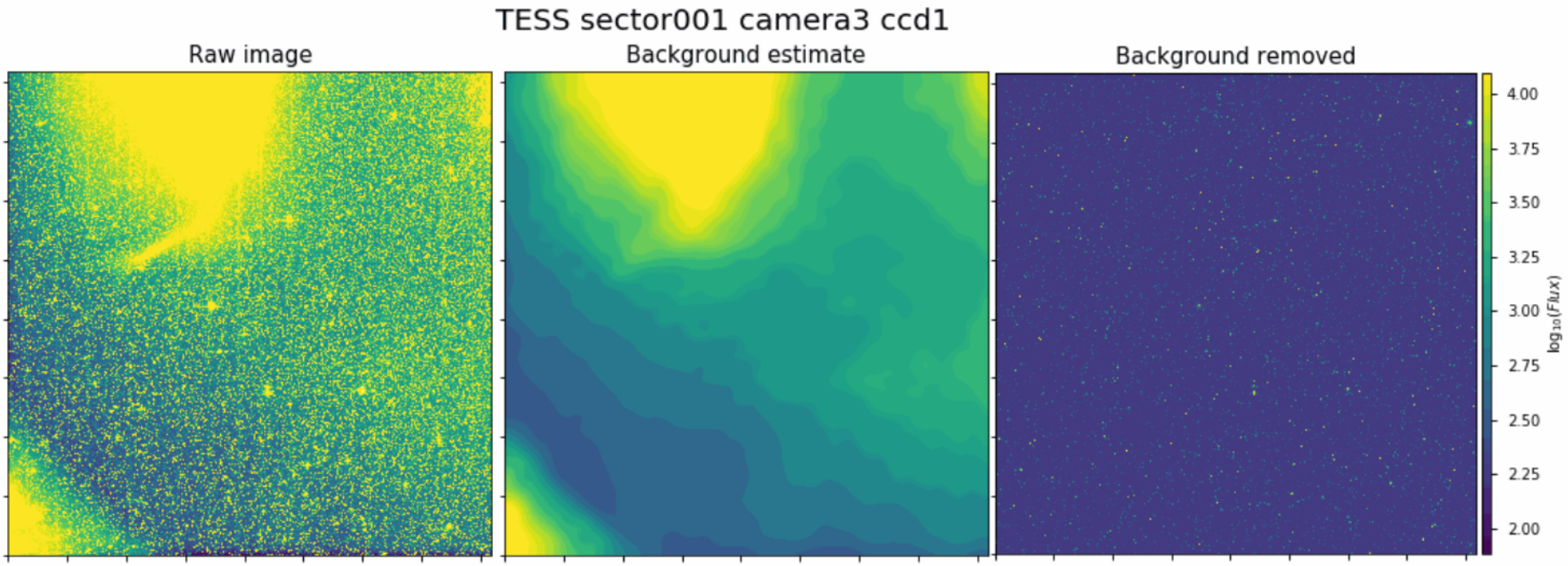


Image credit: Oliver Hall

TASOC FFI backgrounds

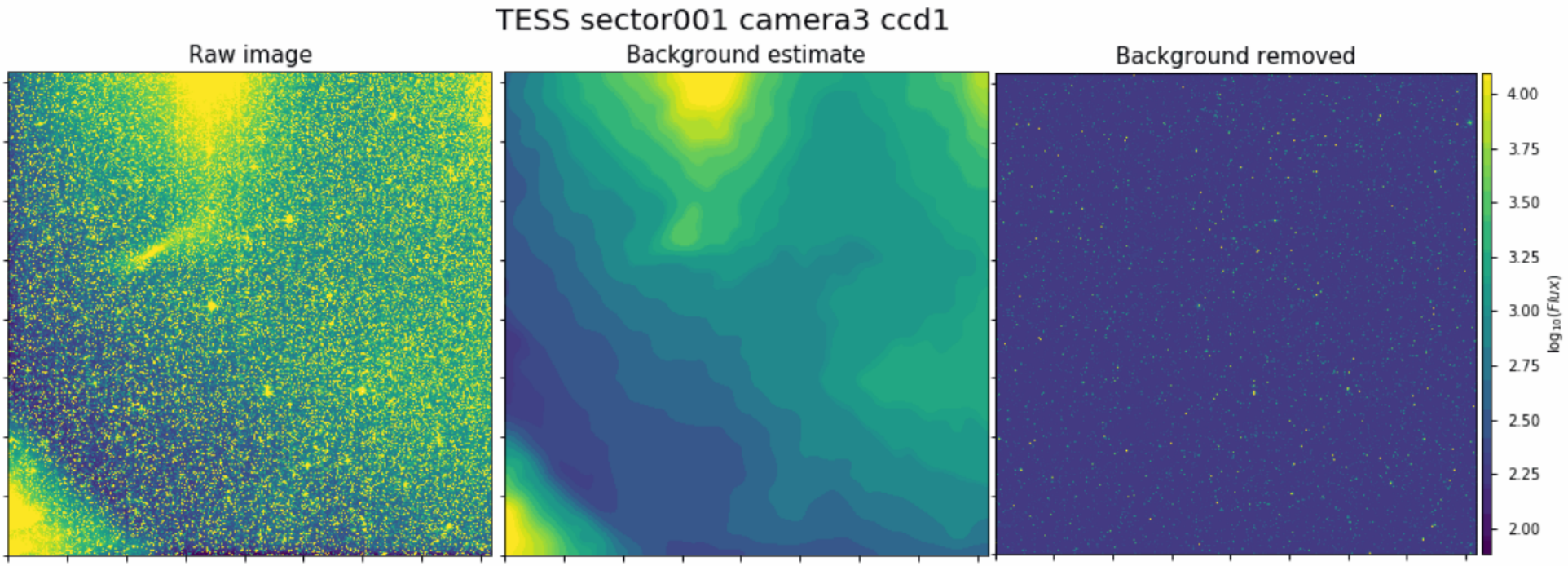


Image credit: Oliver Hall

TASOC FFI backgrounds

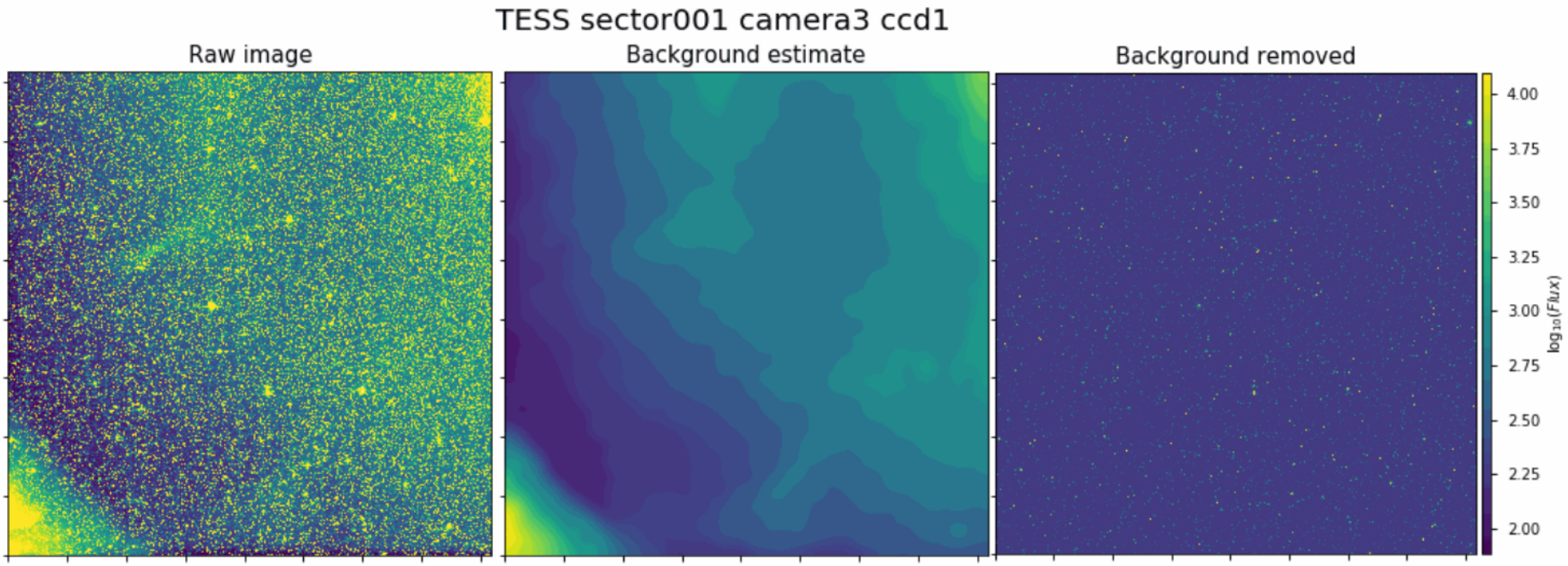


Image credit: Oliver Hall

TASOC FFI backgrounds

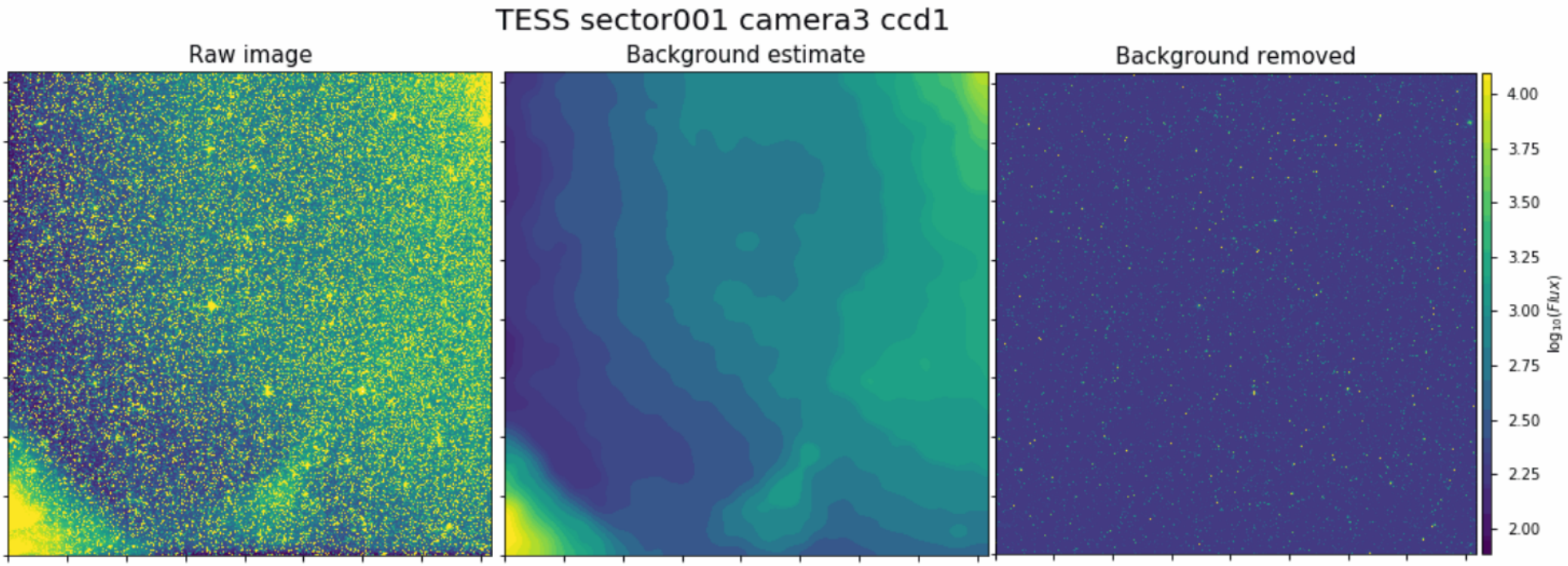


Image credit: Oliver Hall

TASOC FFI backgrounds

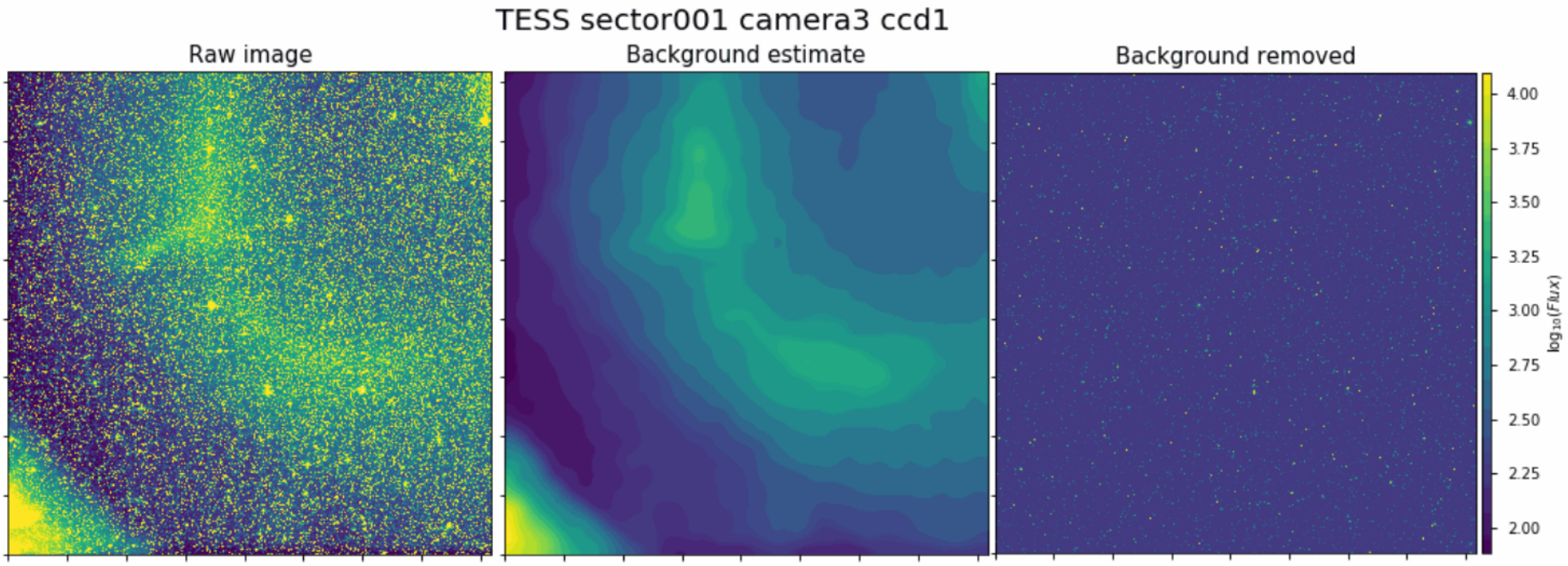
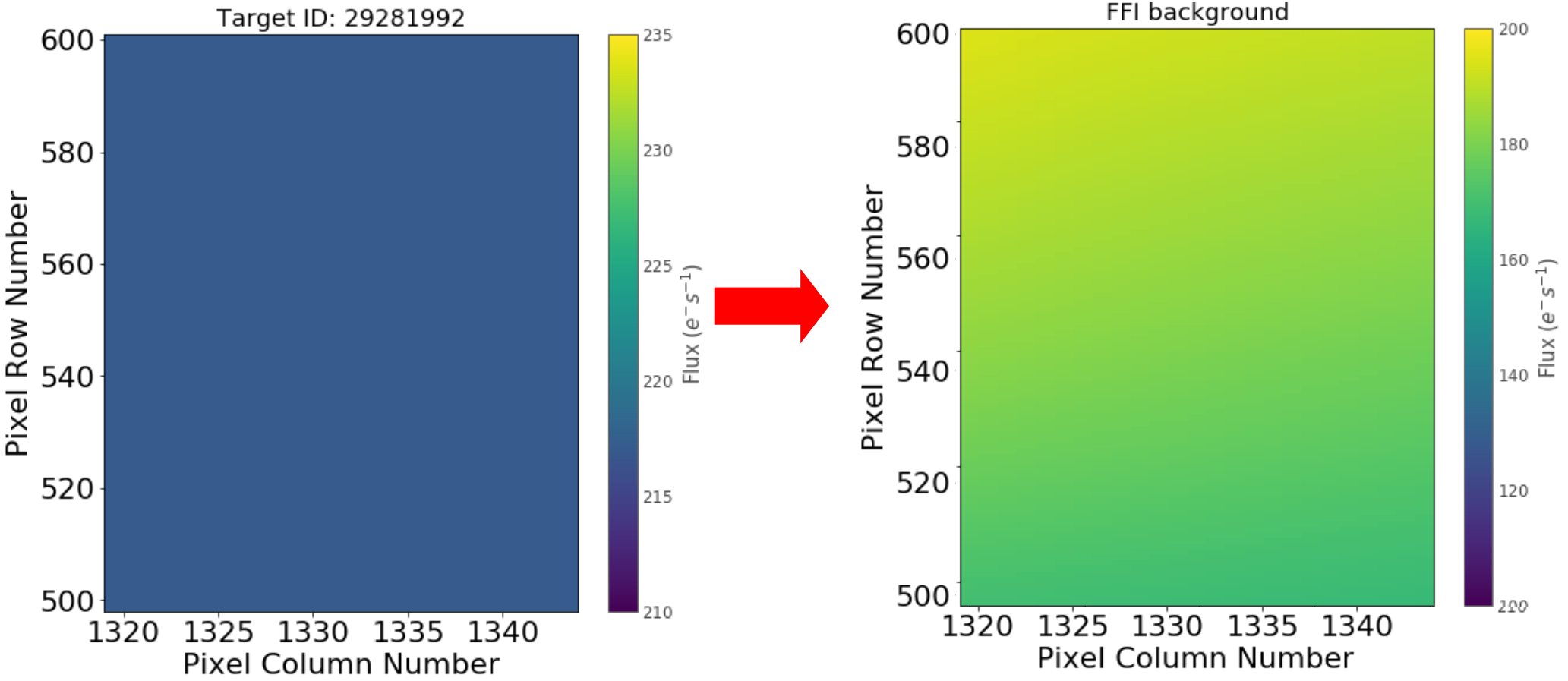
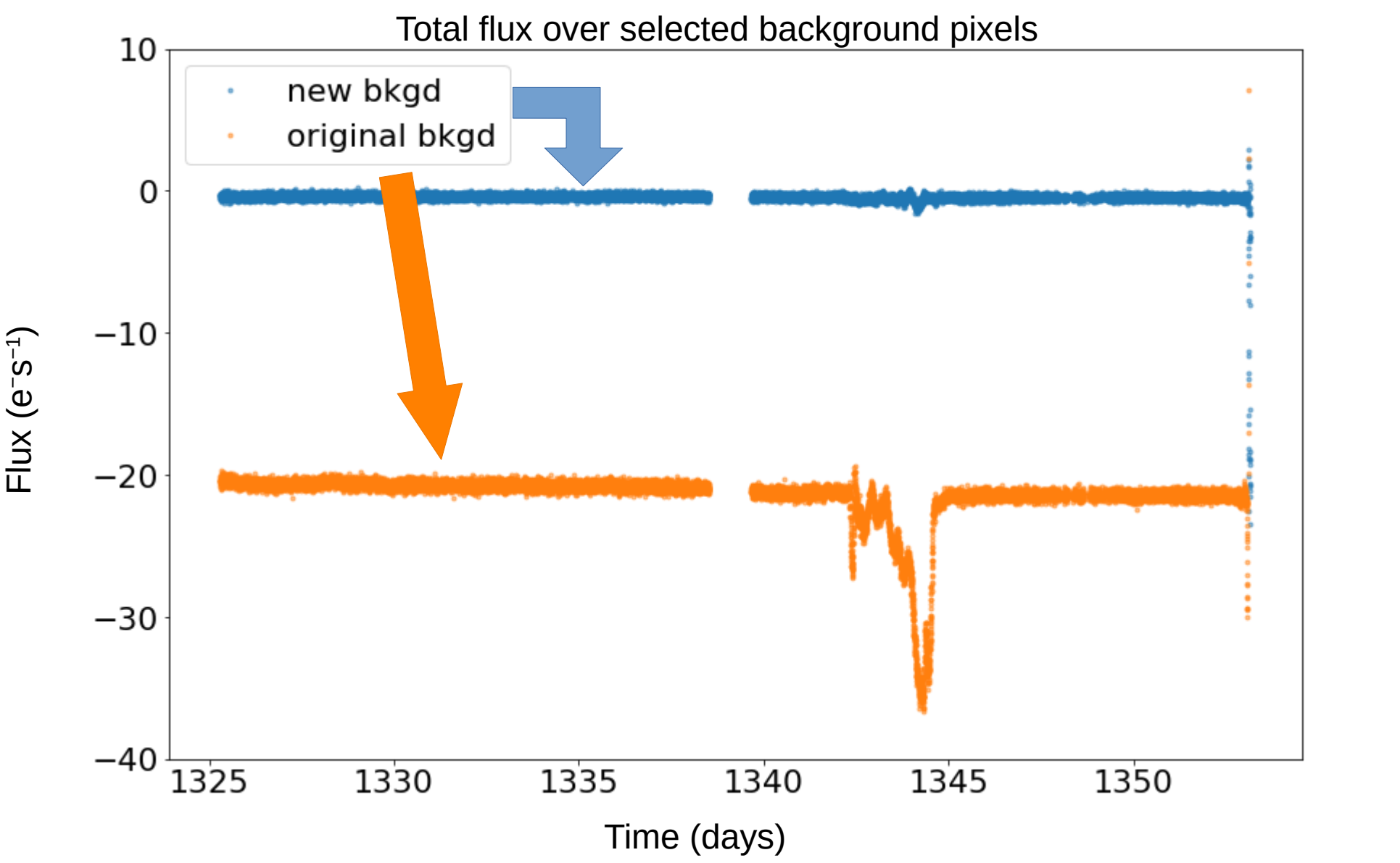
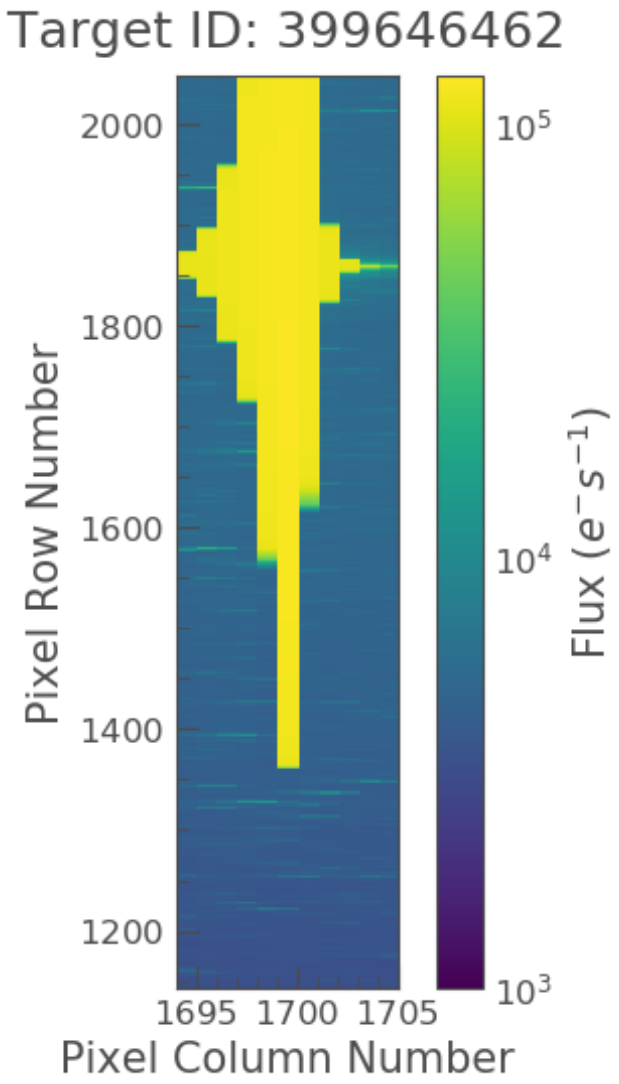


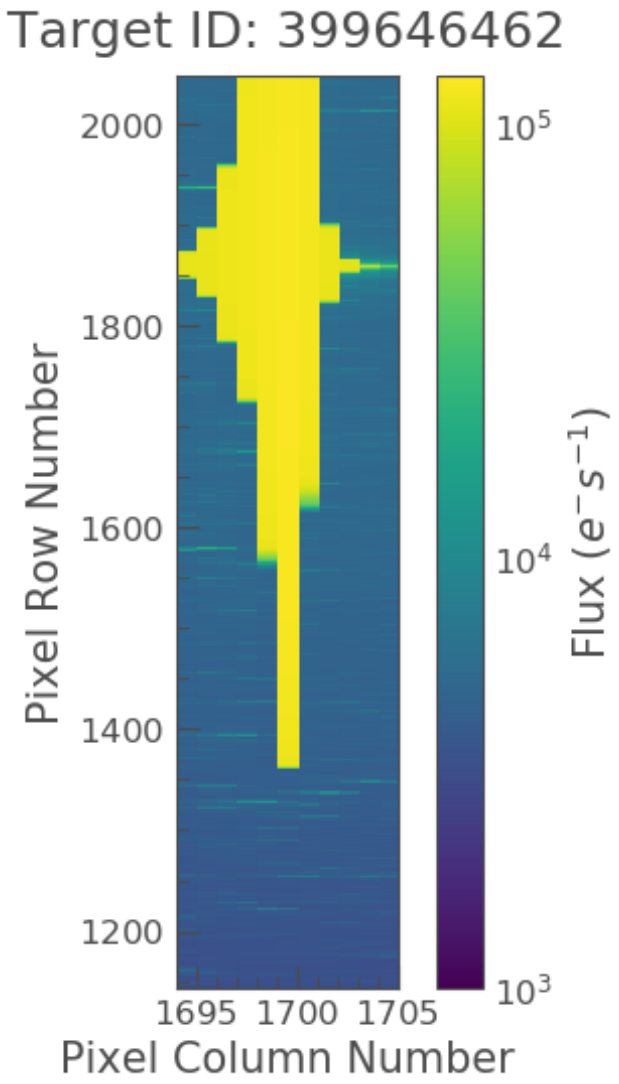
Image credit: Oliver Hall


Target ID: 29281992
Pixel Row Number
600
580
560
540
520
500
1320
1325
1330
1335
1340
Pixel Column Number
235
230
225
220
215
210
Flux (e^-s^{-1})
FFI background
Pixel Row Number
600
580
560
540
520
500
1320
1325
1330
1335
1340
Pixel Column Number
200
180
160
140
120
Flux (e^-s^{-1})


Total flux over selected background pixels
new bkgd
original bkgd
10
0
−10
−20
−30
−40
Flux (e⁻s⁻¹)
1325
1330
1335
1340
1345
1350
Time (days)



Aperture Losses



Aperture Losses

‘Halo’ photometry

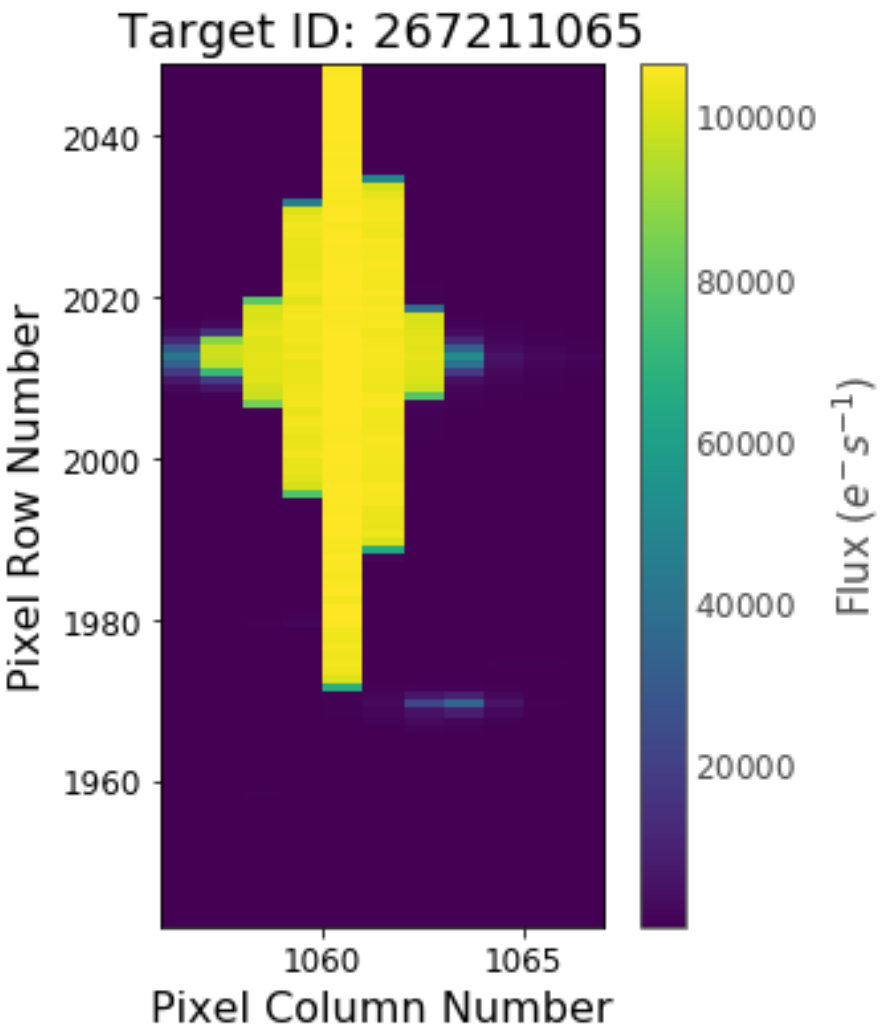
White et al. 2017

Pope et al. (in prep.)

Code:
https://github.com/hvidy/halophot

***K2* light curves:**
https://github.com/benjaminpope/k2halo

β Hydri


Target ID: 267211065
Pixel Row Number
2040
2020
2000
1980
1960
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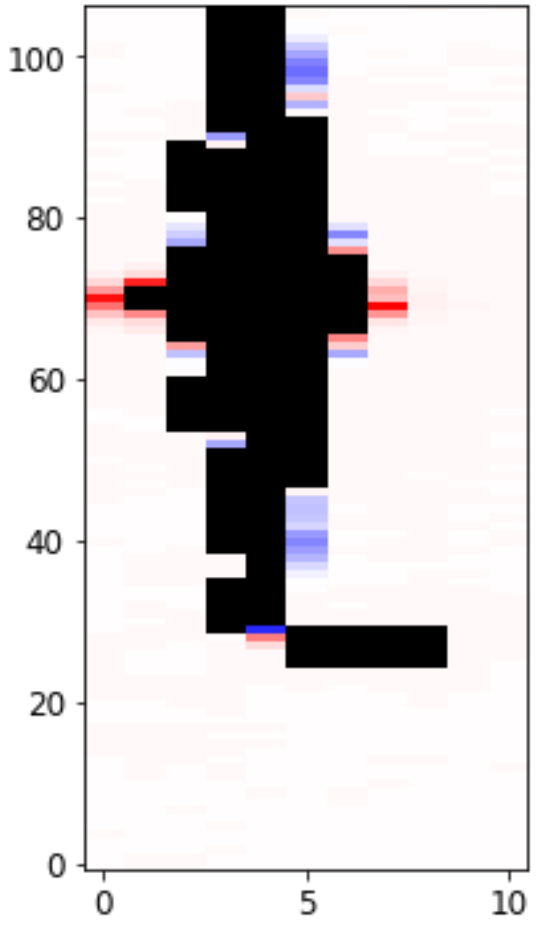
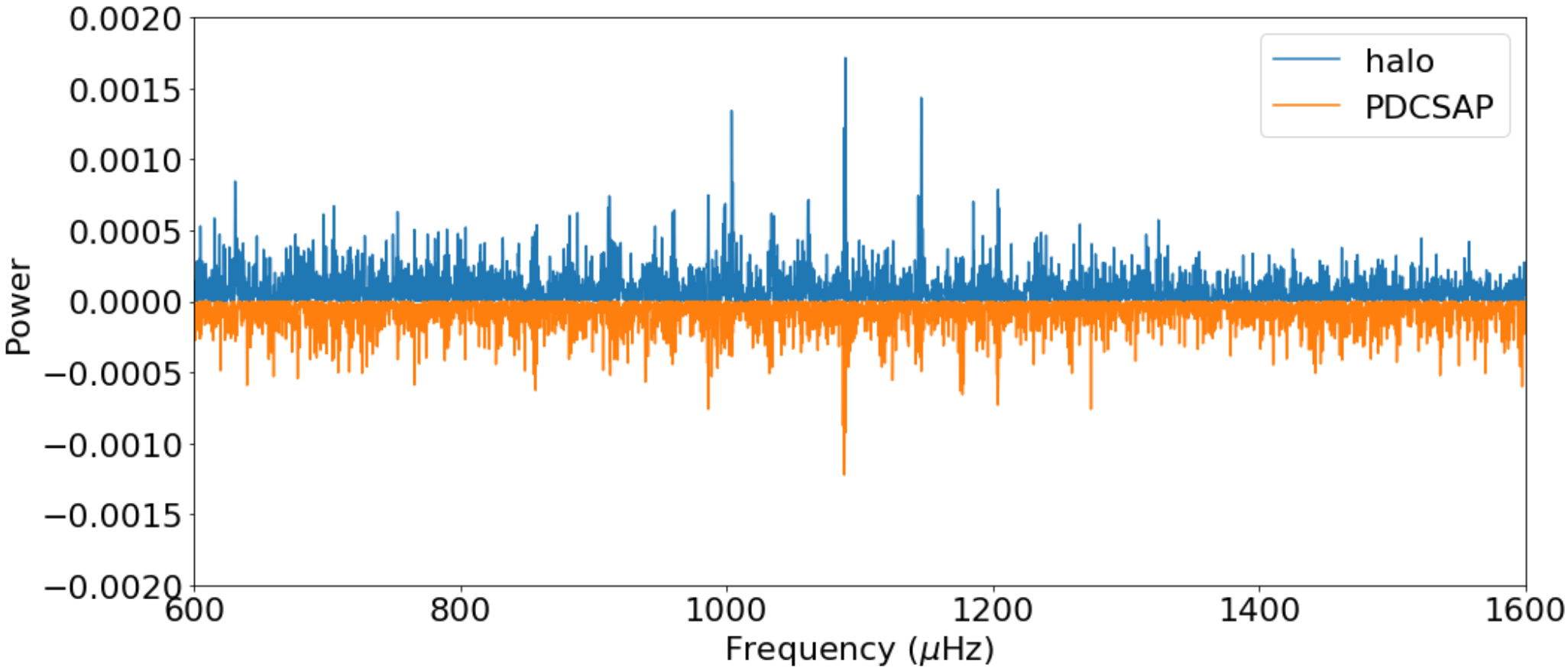
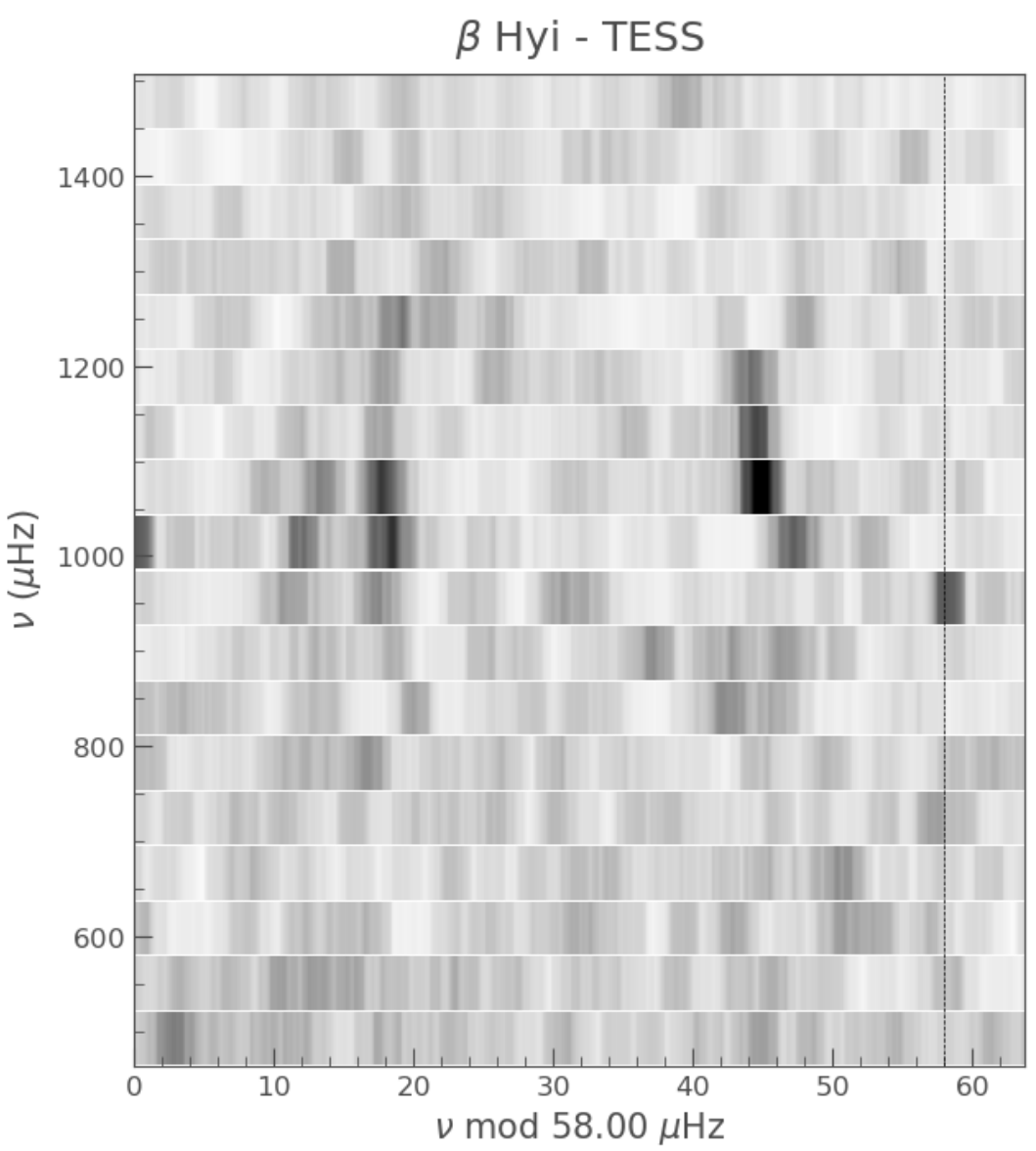
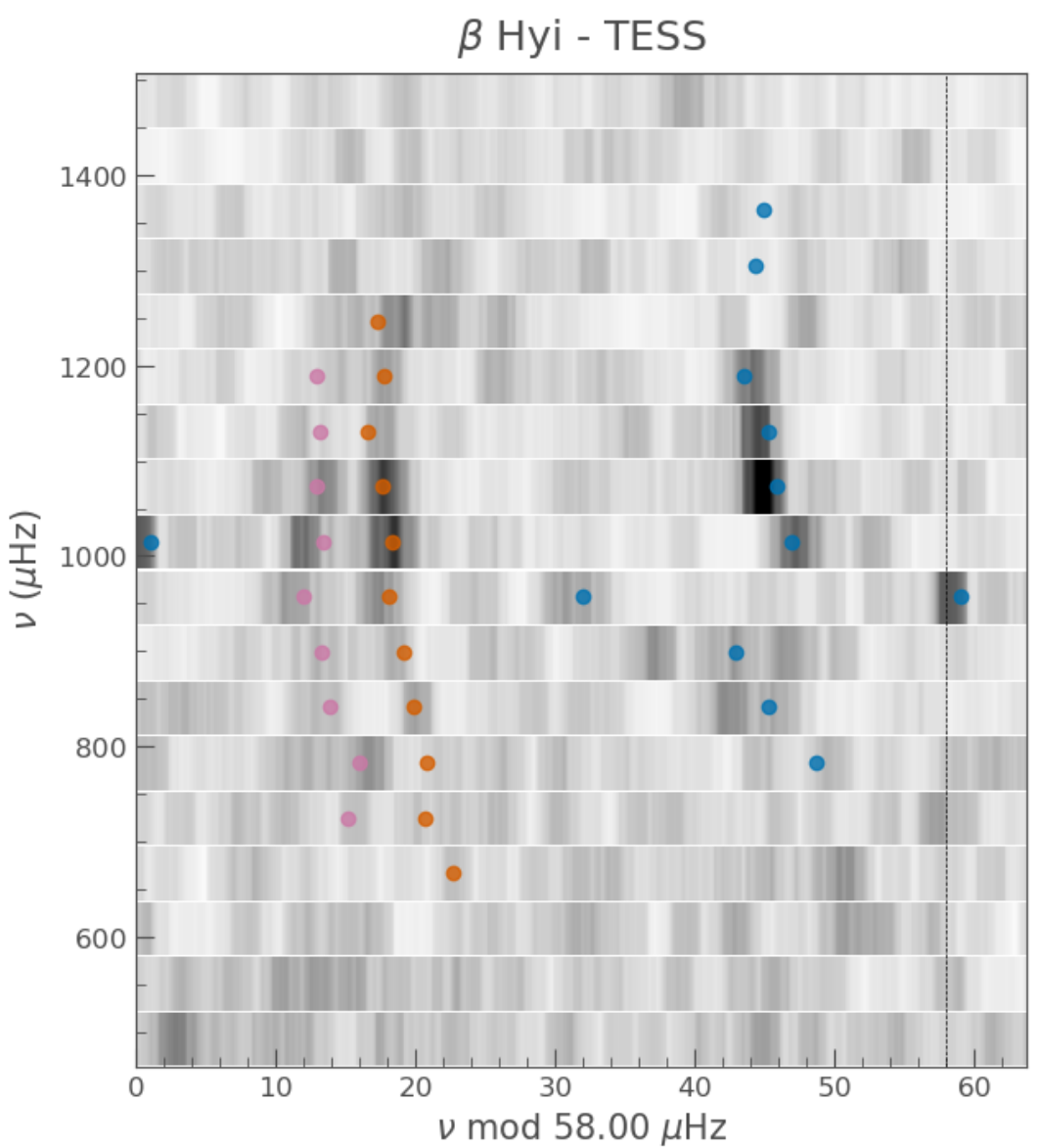
Pixel Column Number
100000
80000
60000
40000
20000
Flux (e^-s^{-1})

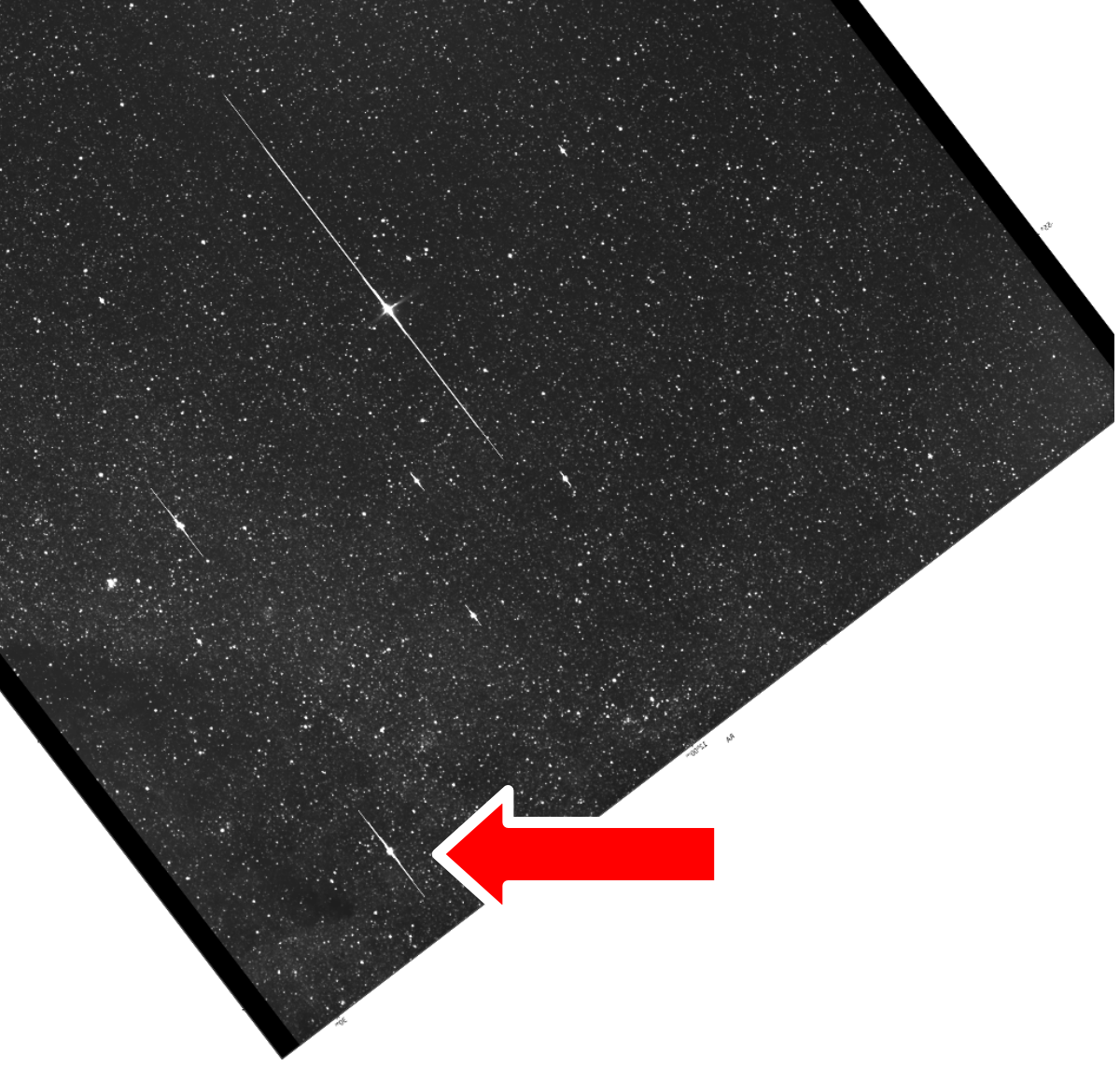

100
80
60
40
20
0
0
5
10


0.0020
0.0015
0.0010
0.0005
0.0000
−0.0005
−0.0010
−0.0015
−0.0020
Power
600
800
1000
1200
1400
1600
Frequency (μHz)
halo
PDCSAP


β Hyi - TESS
1400
1200
1000
800
600
ν (μHz)
0
10
20
30
40
50
60
ν mod 58.00 μHz



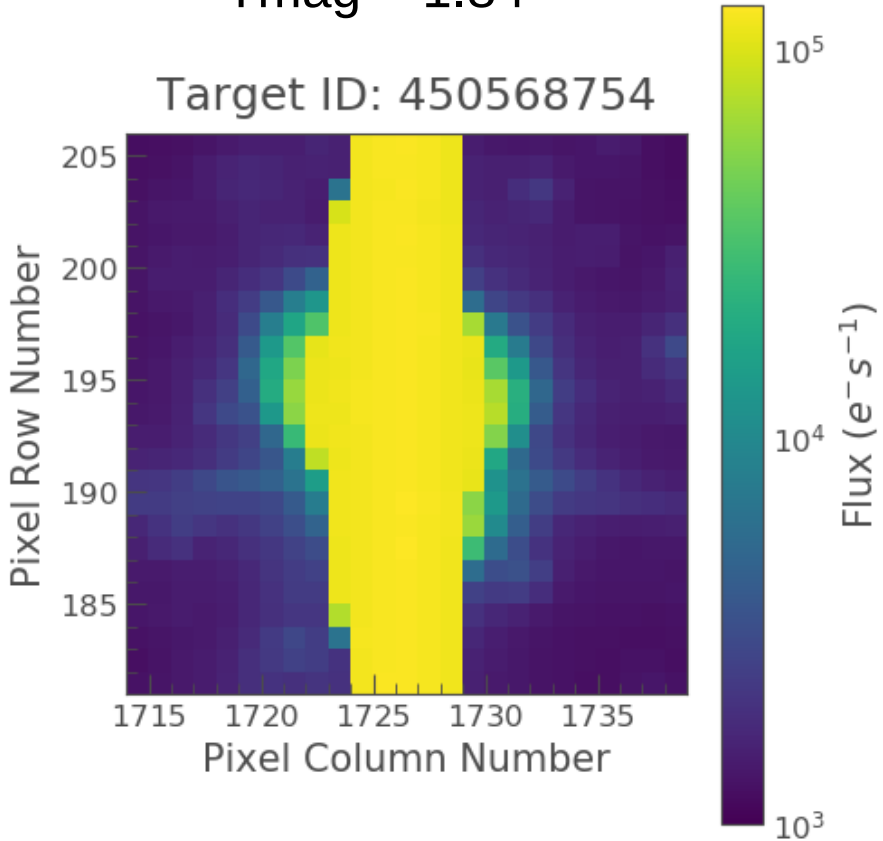
Frequencies from
Brandão et al. 2011

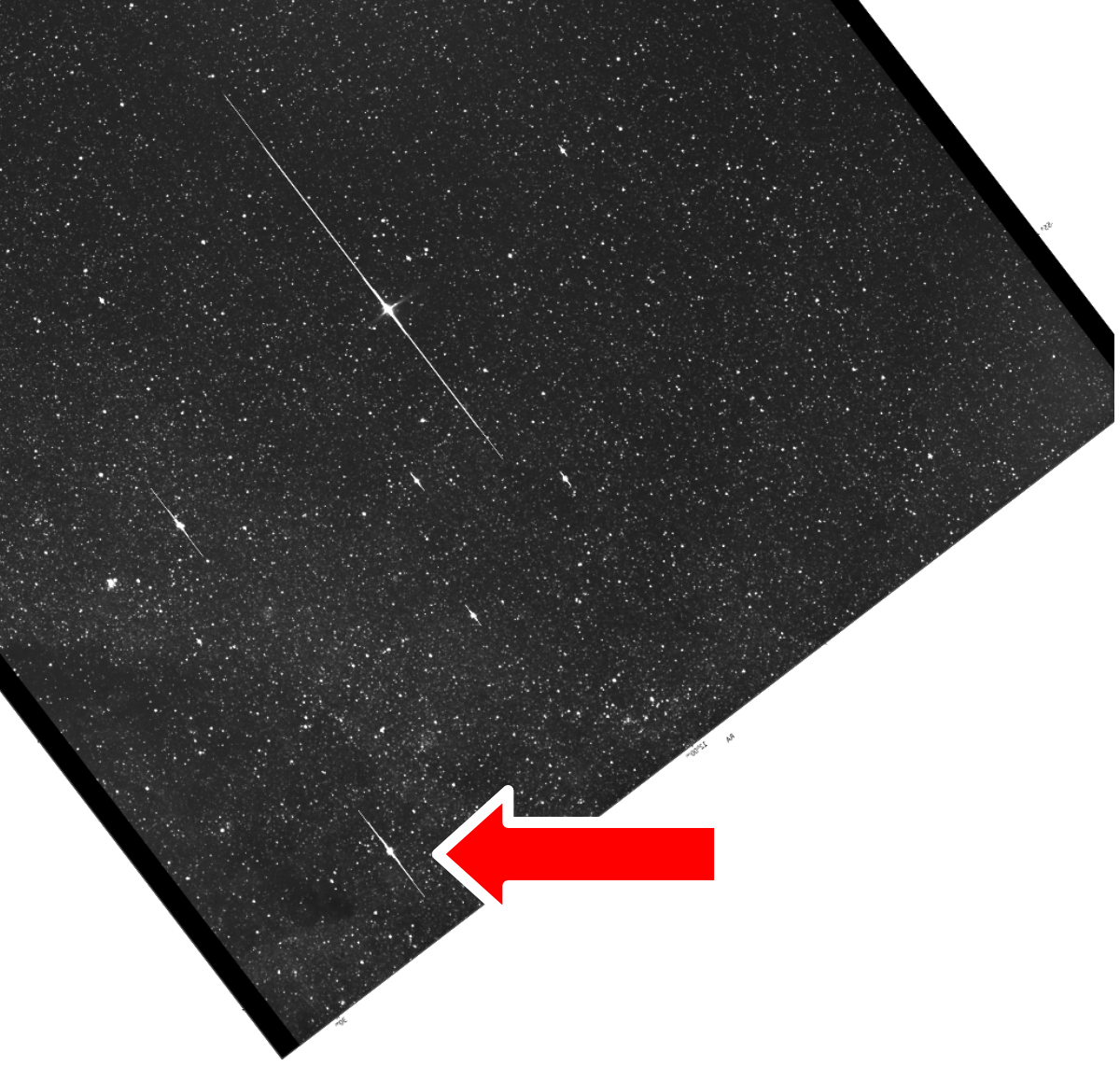


α Cru (Acrux)

B0.5IV + B1V

Tmag = 1.84

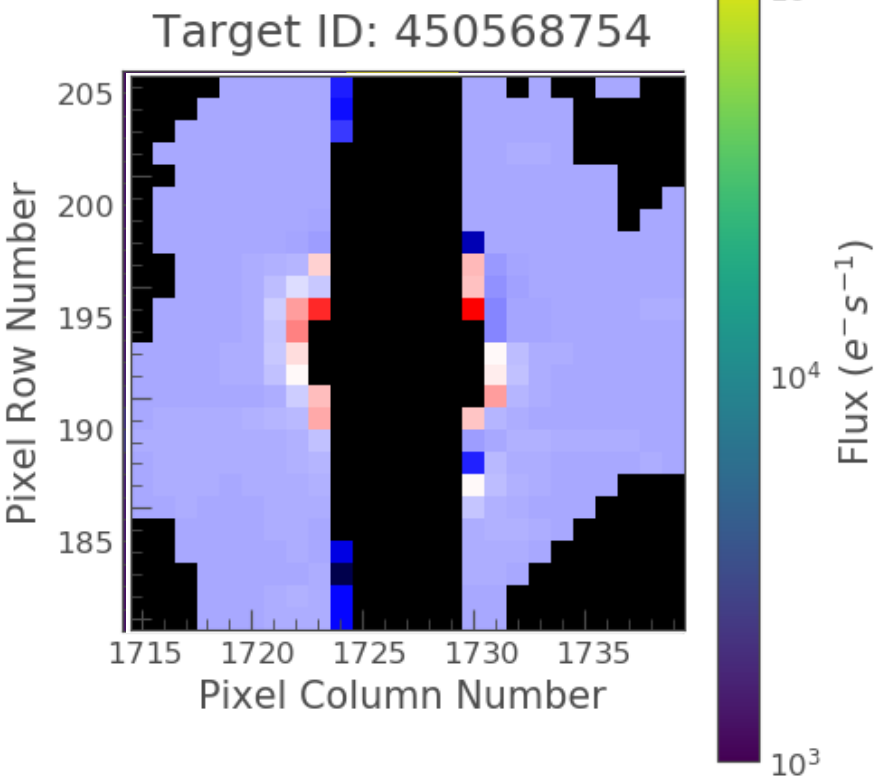




α Cru (Acrux)

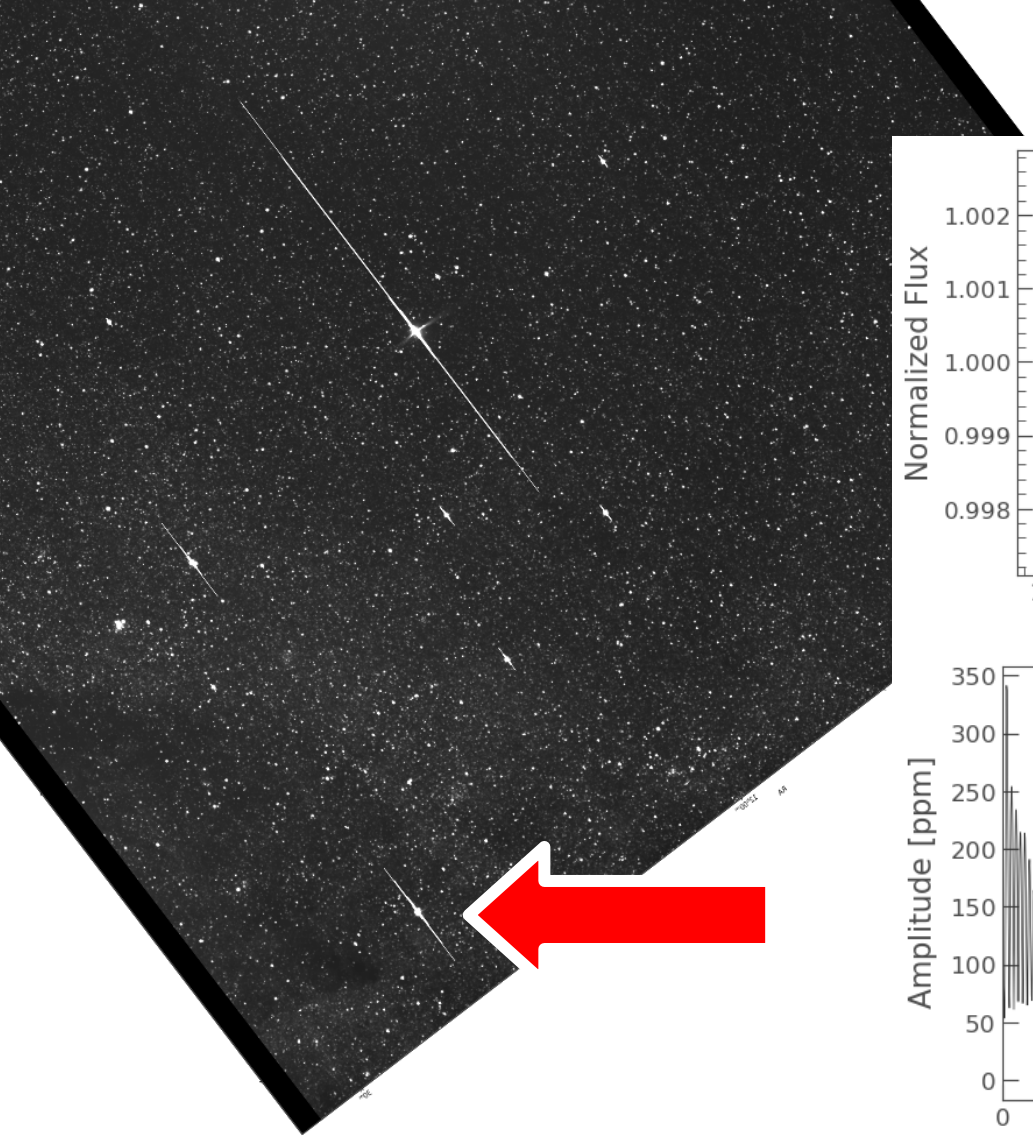
B0.5IV + B1V

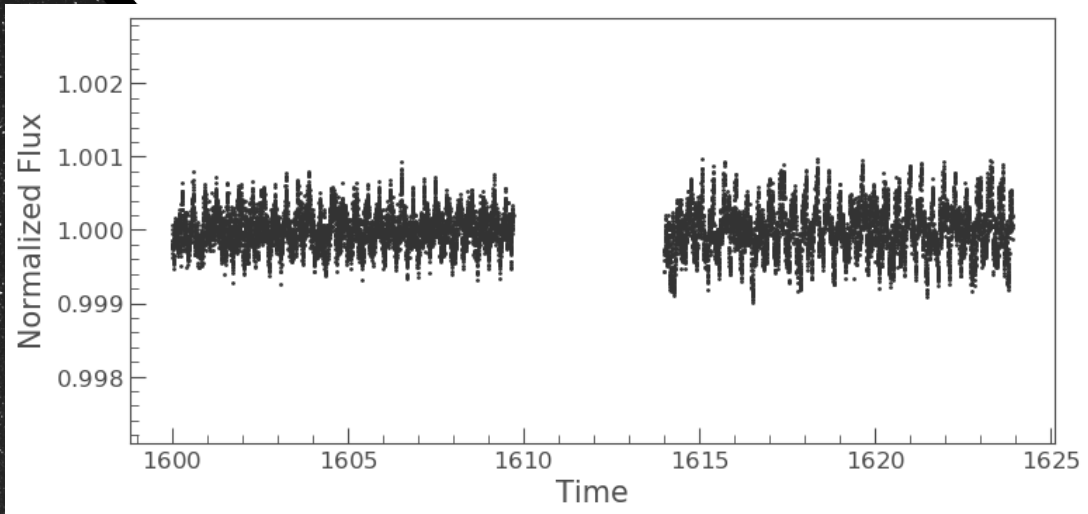
Tmag = 1.84

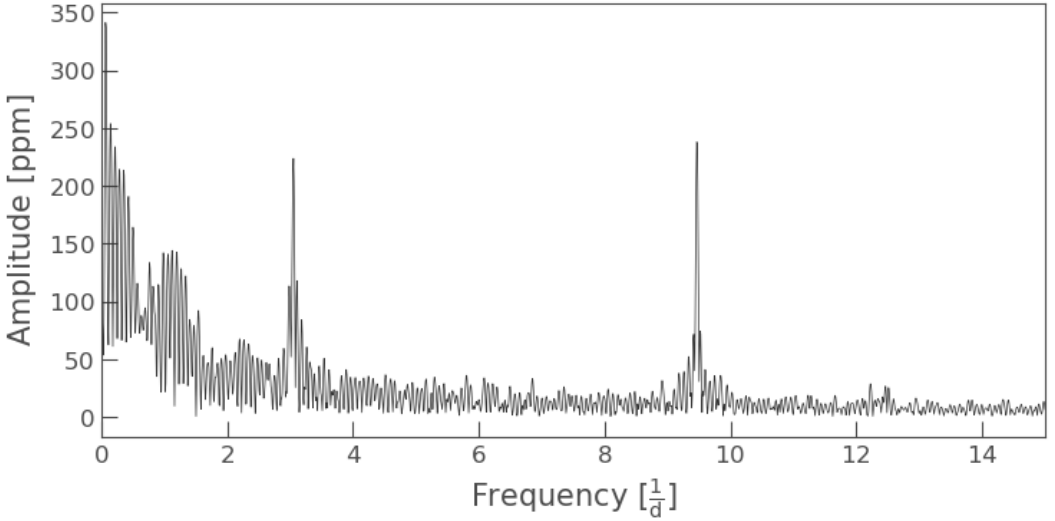


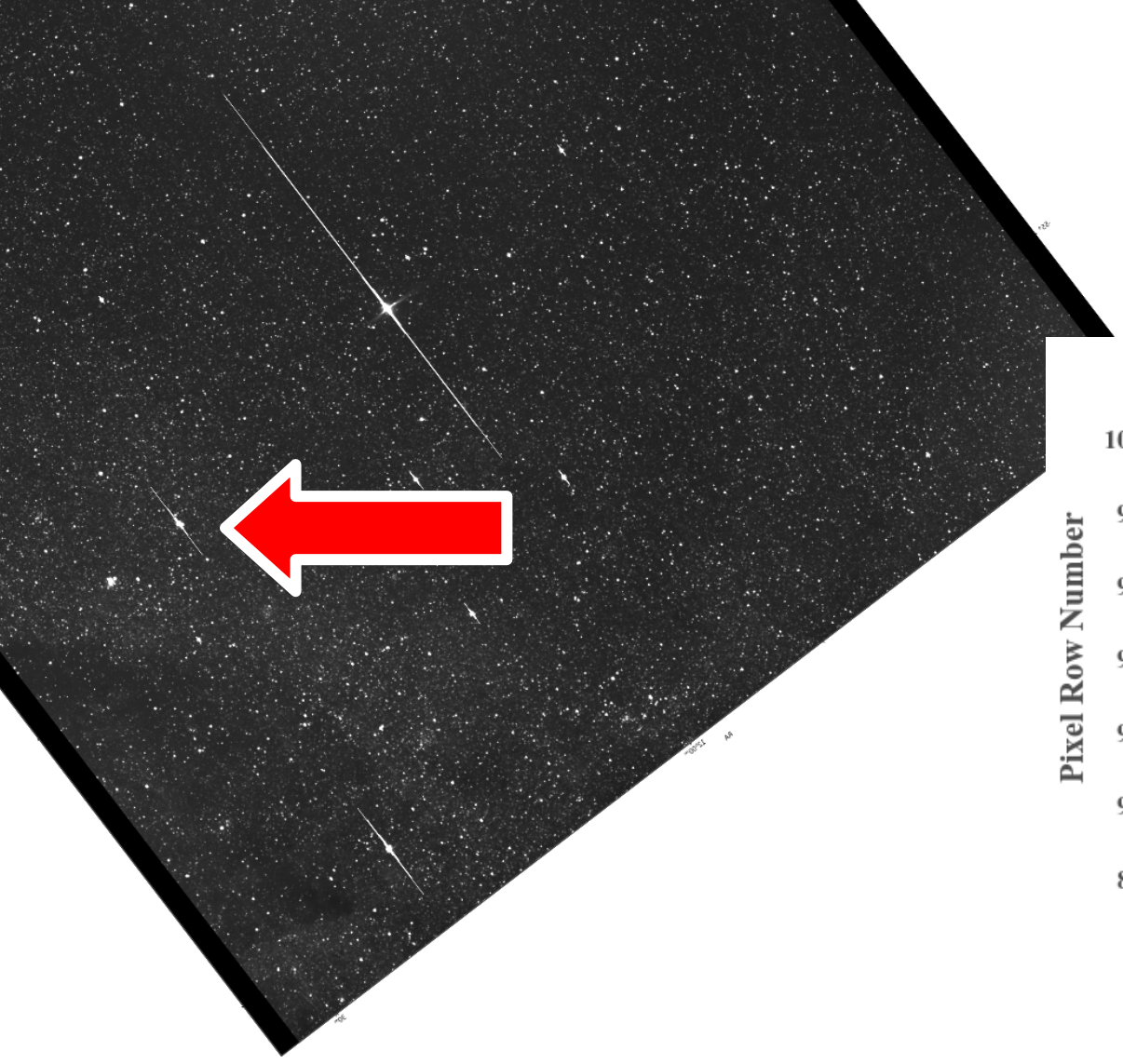
α Cru (Acrux)

B0.5IV + B1V





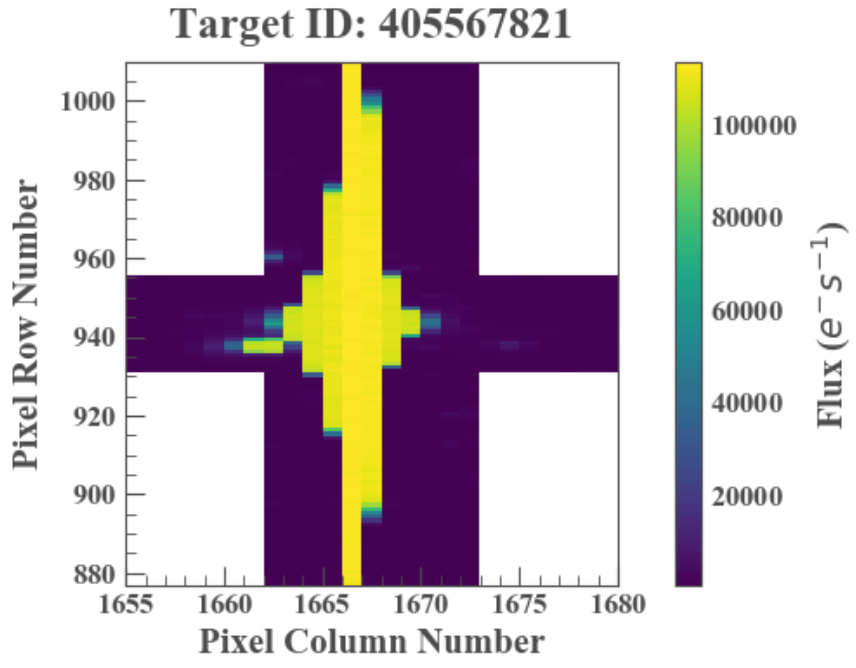




β Cru (Mimosa)

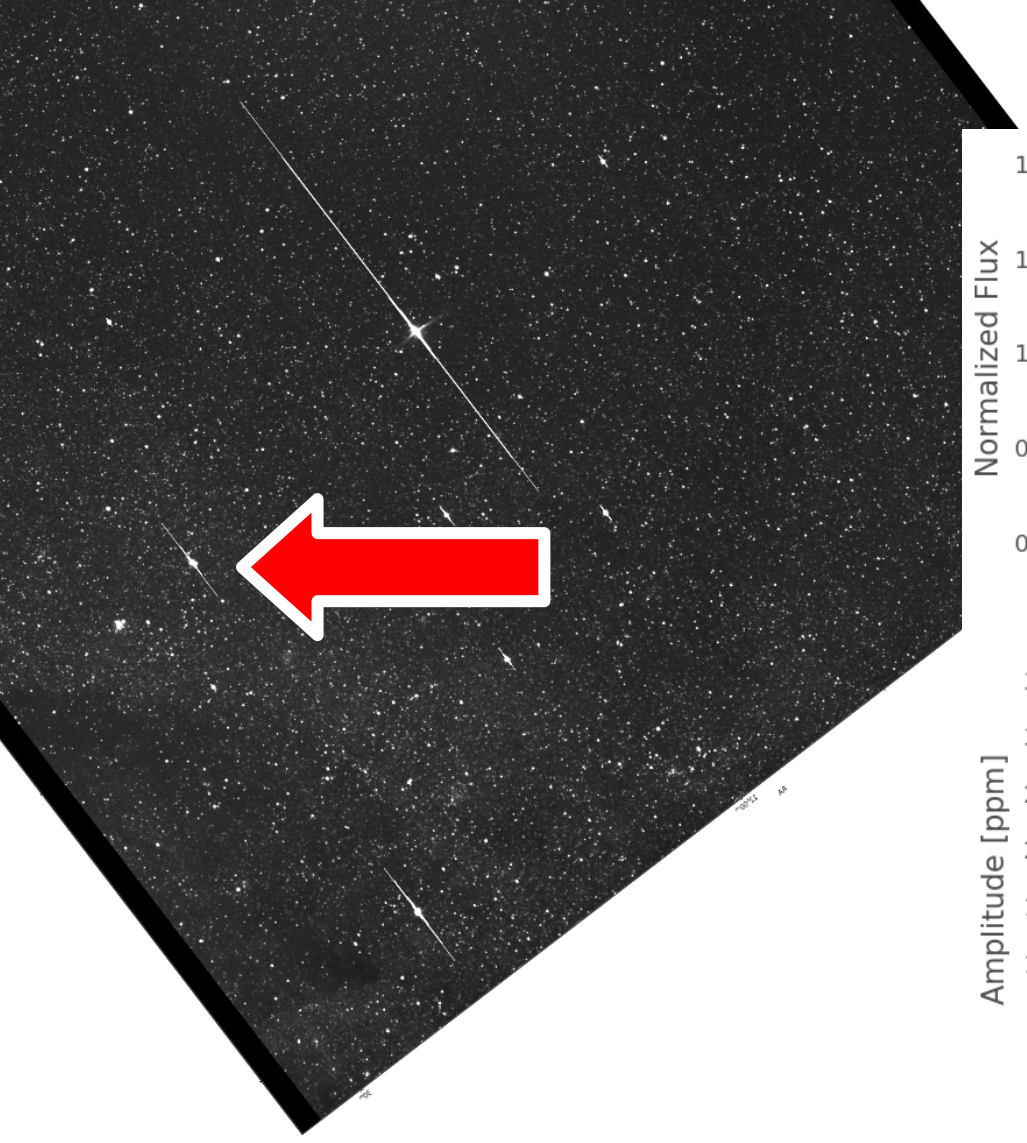
B1IV

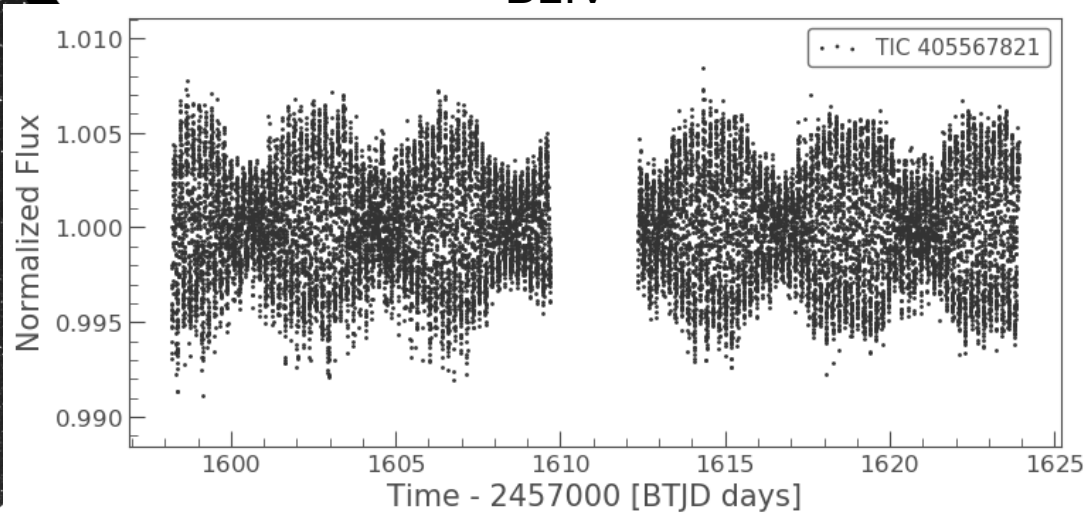
Tmag = 2.28

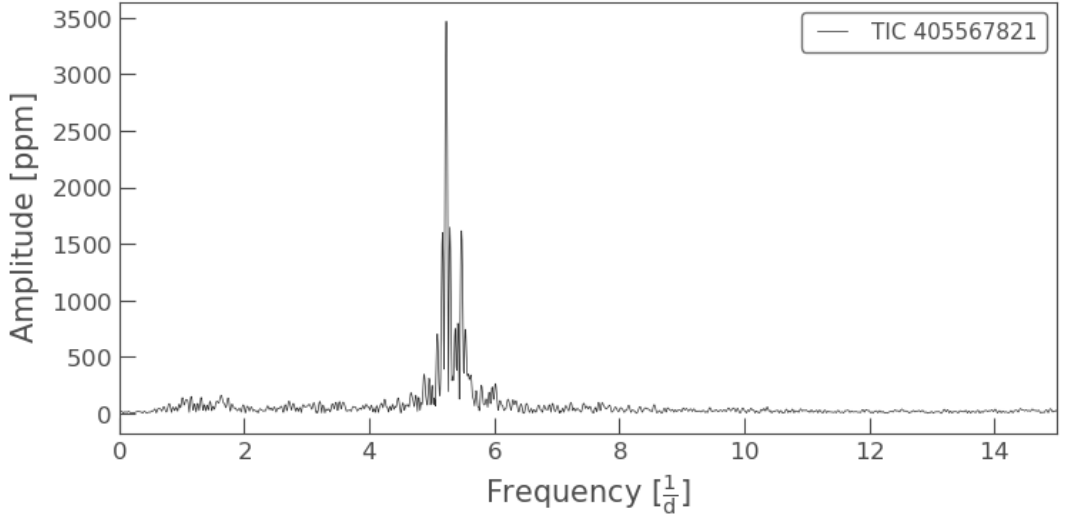


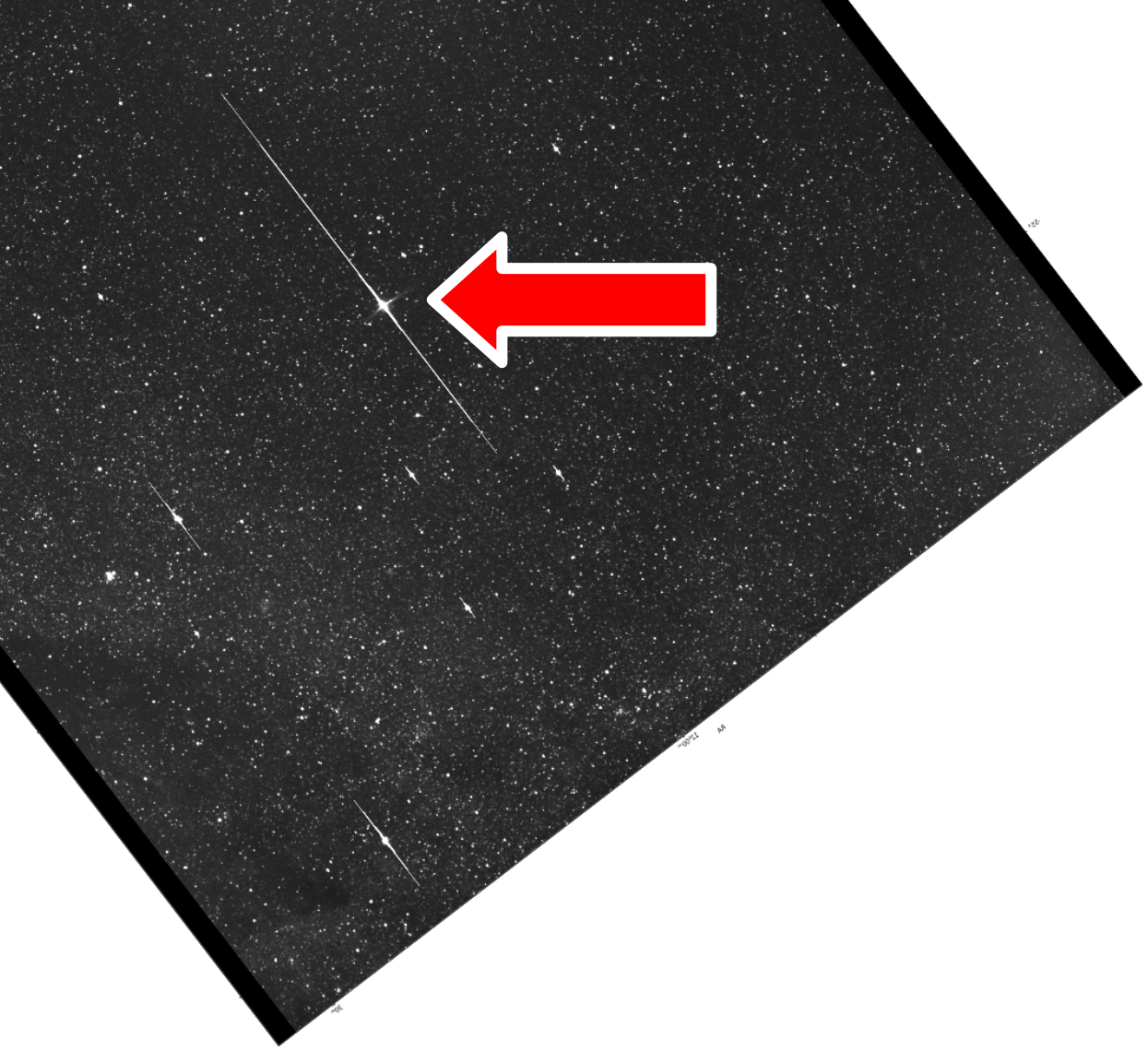
β Cru (Mimosa)

B1IV





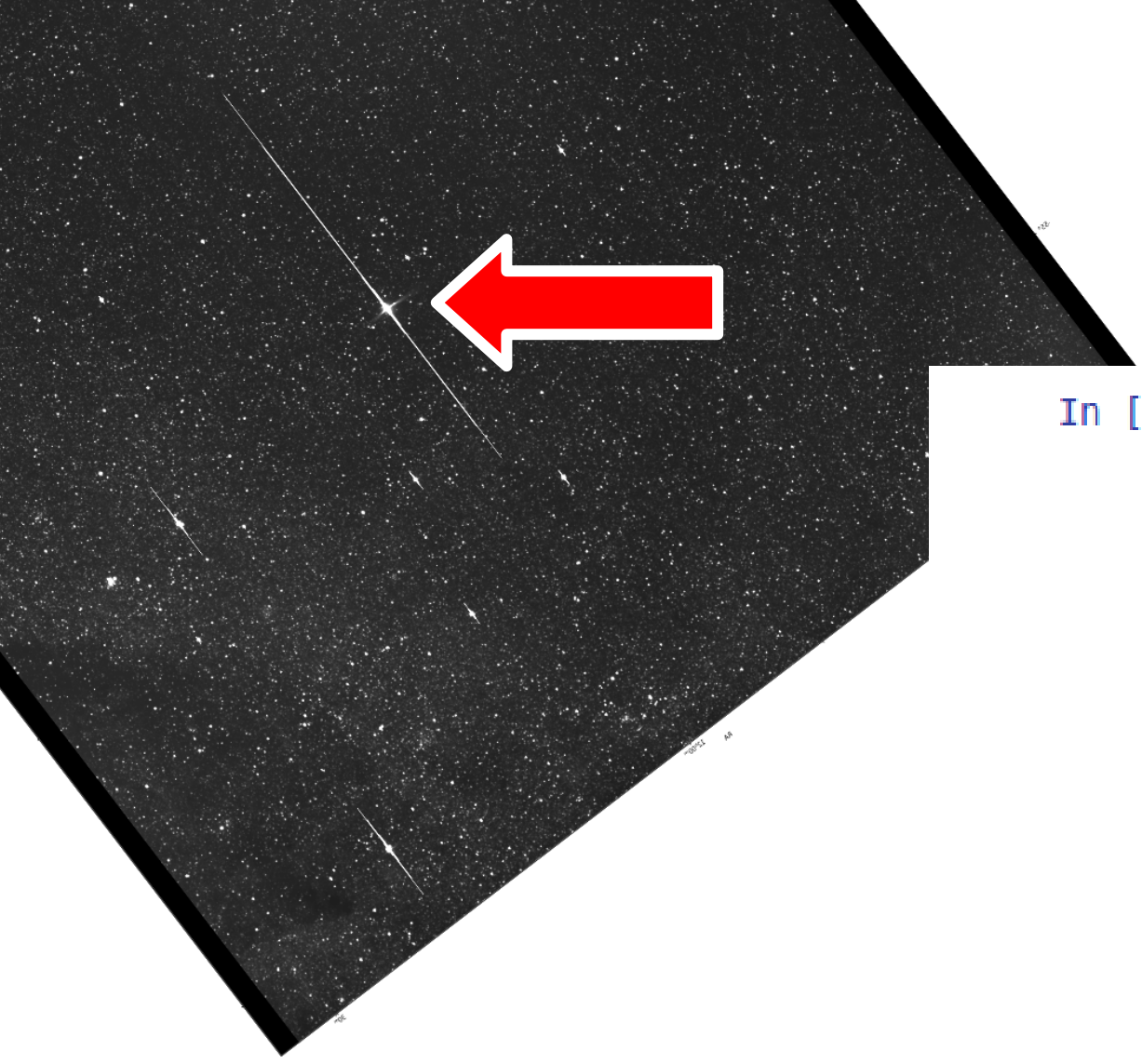




γ Cru (Gacrux)

M3.5III

Tmag = -1.04



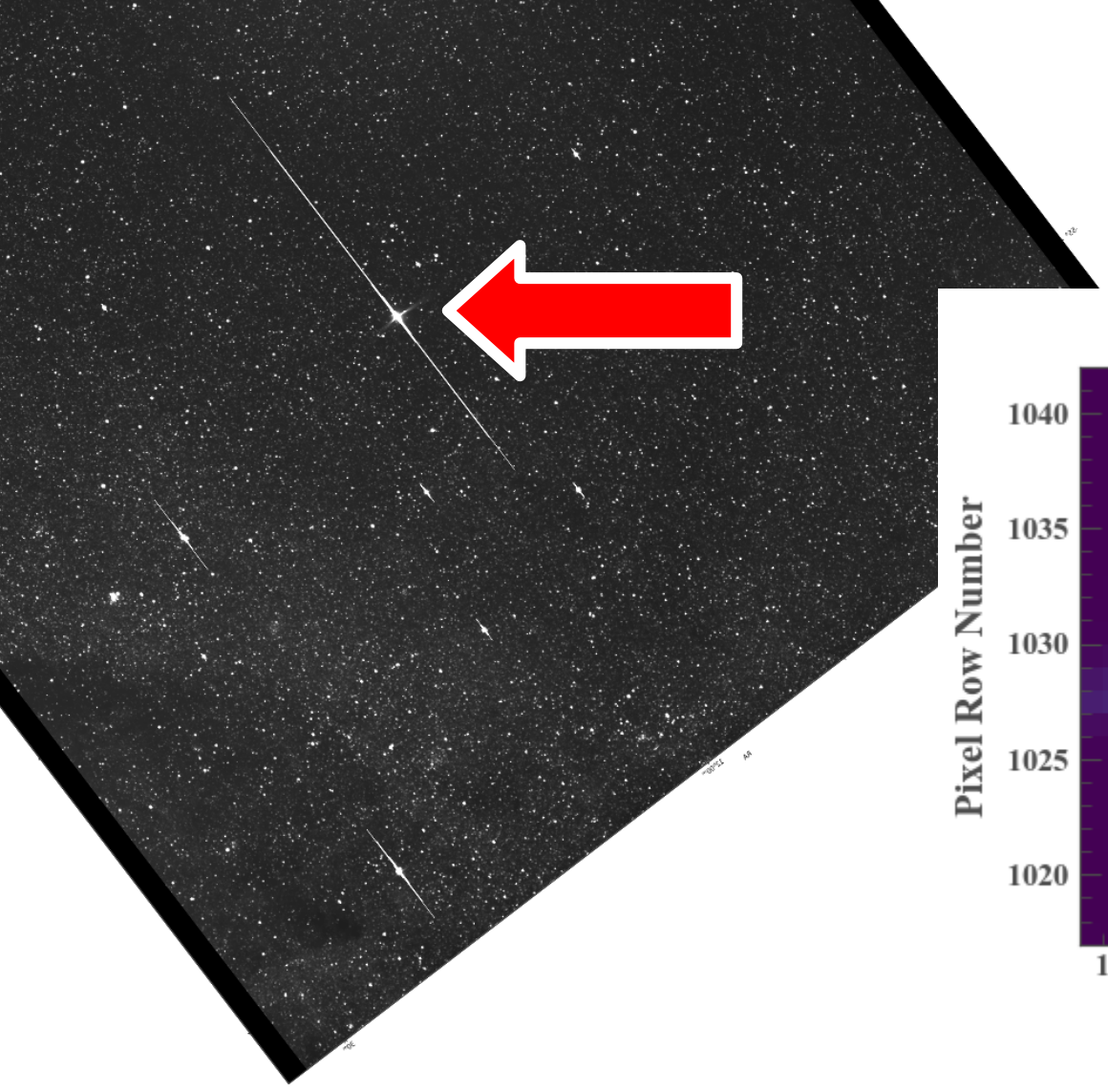
γ Cru (Gacrux)

M3.5III

Tmag = -1.04

```
In [71]: fname6 = '../data/gamCru/tess2019
         tpf6 = halo_tpf(fname6)
```

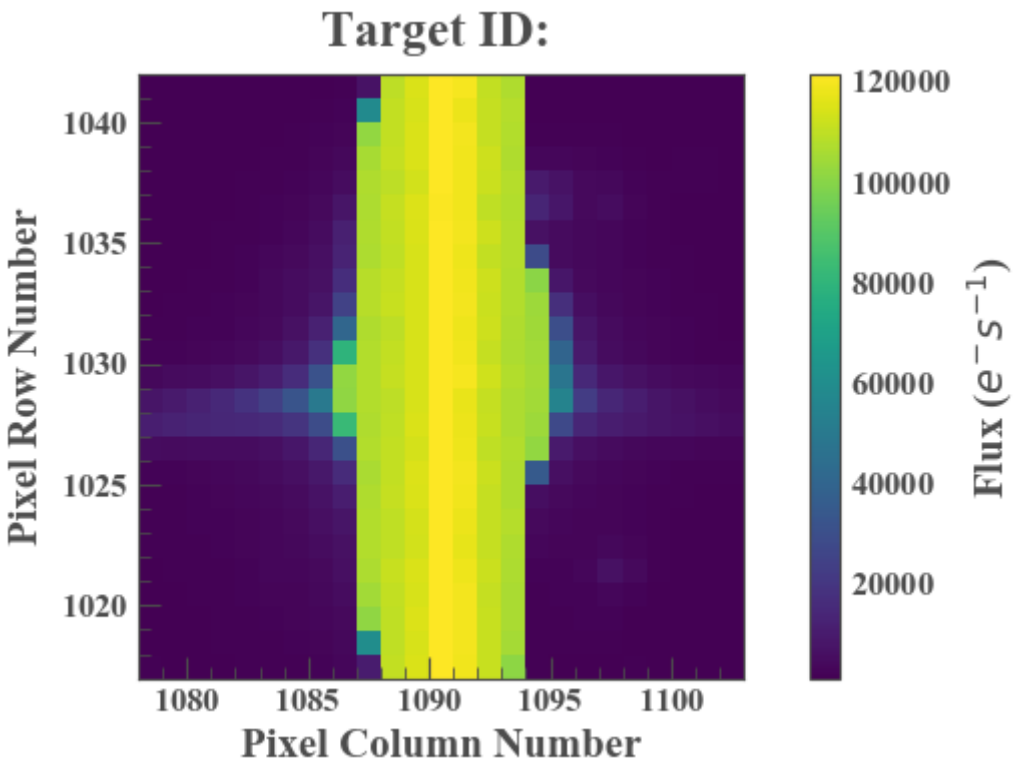
```
---------------------------------
MemoryError
<ipython-input-71-71b501567dec> i
      1 fname6 = '../data/gamCru/
----> 2 tpf6 = halo_tpf(fname6)

~/anaconda3/lib/python3.7/site-pa
```

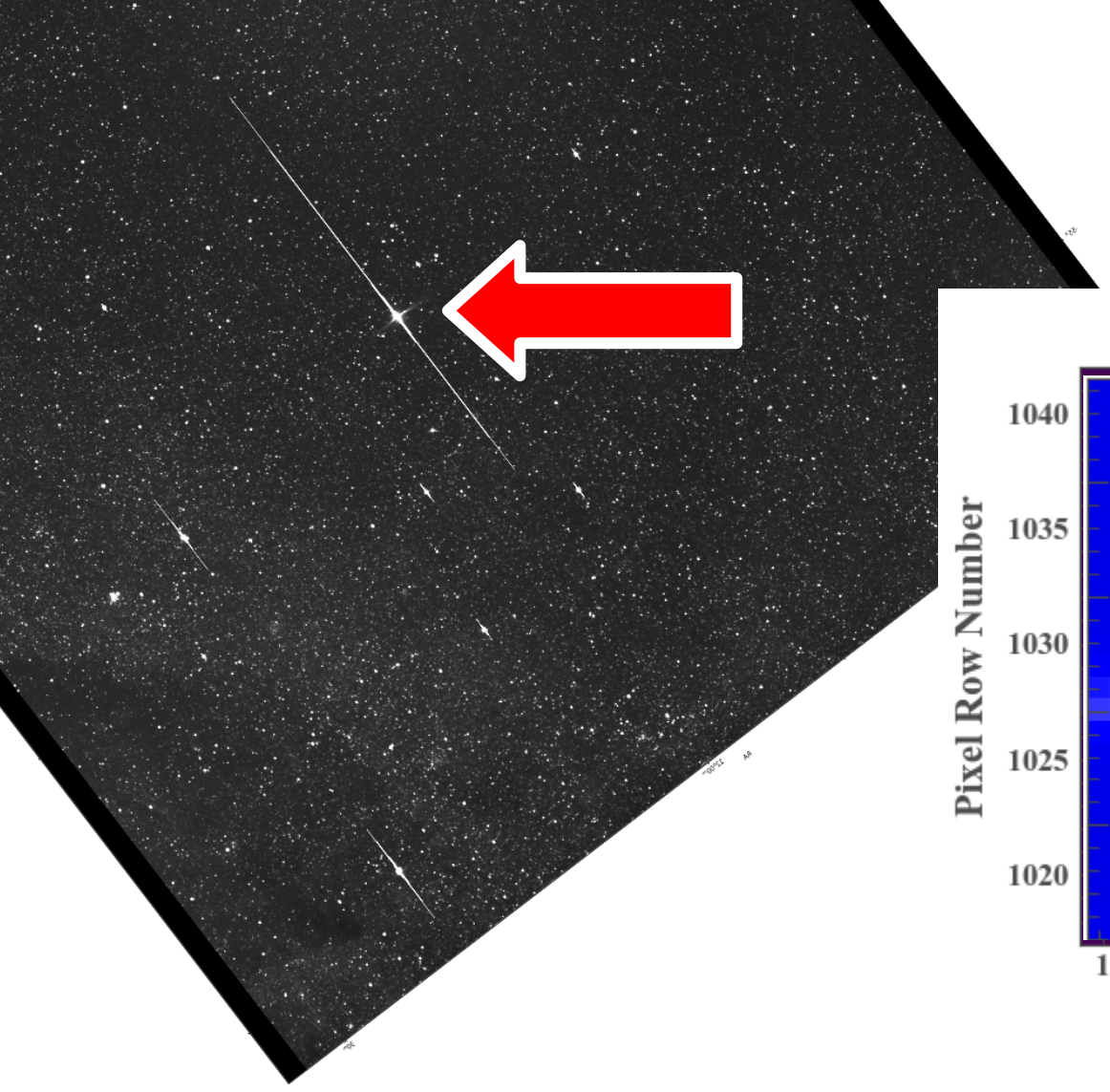


γ Cru (Gacrux)

M3.5III

Tmag = -1.04

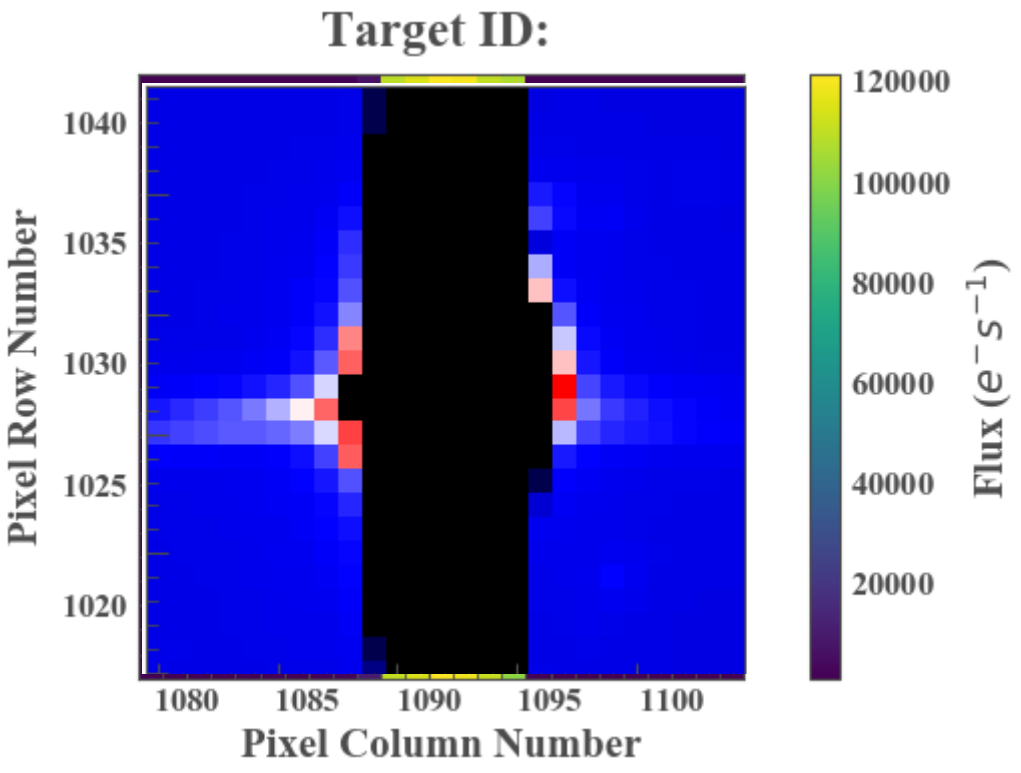




γ Cru (Gacrux)

M3.5III

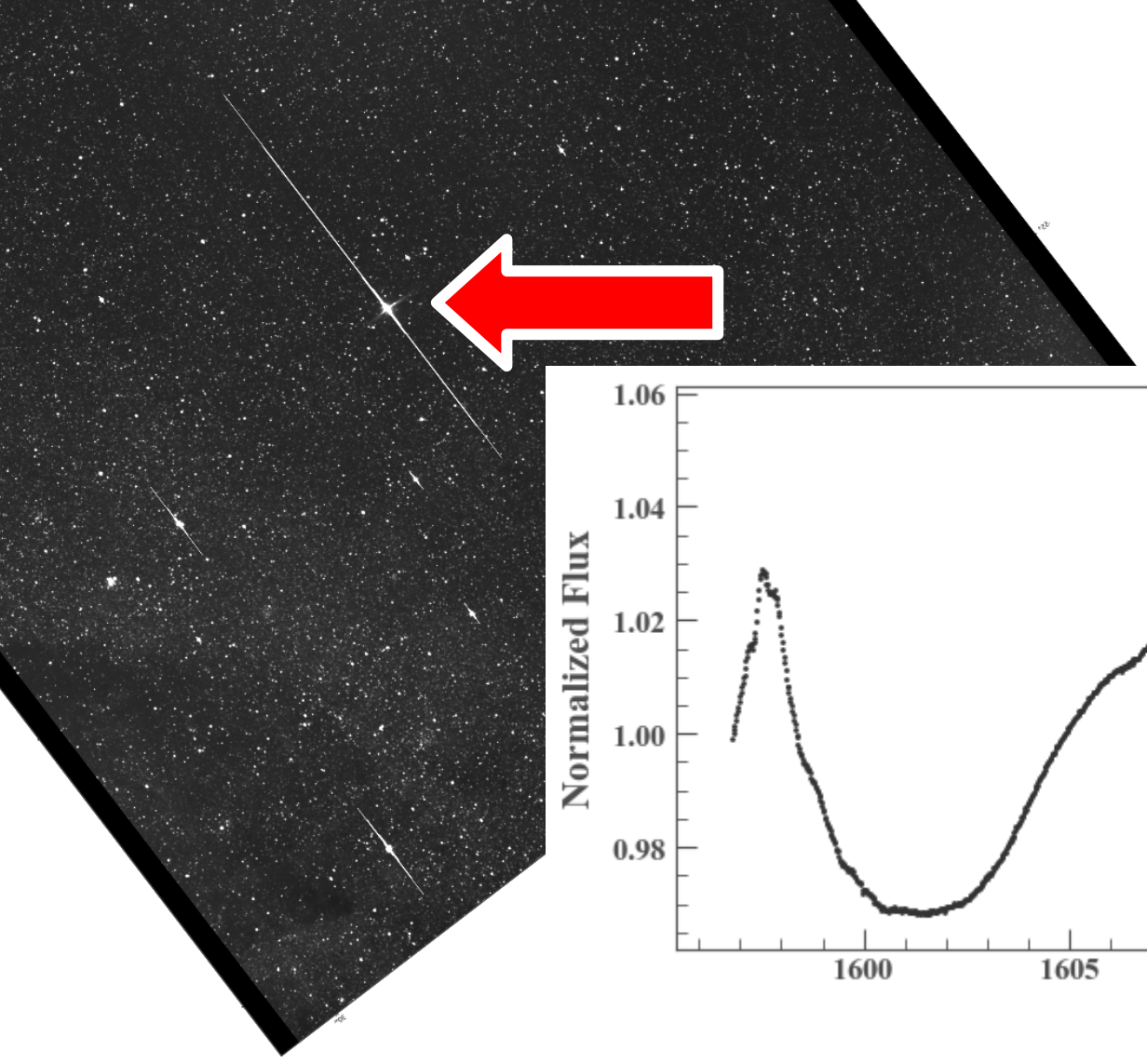
Tmag = -1.04

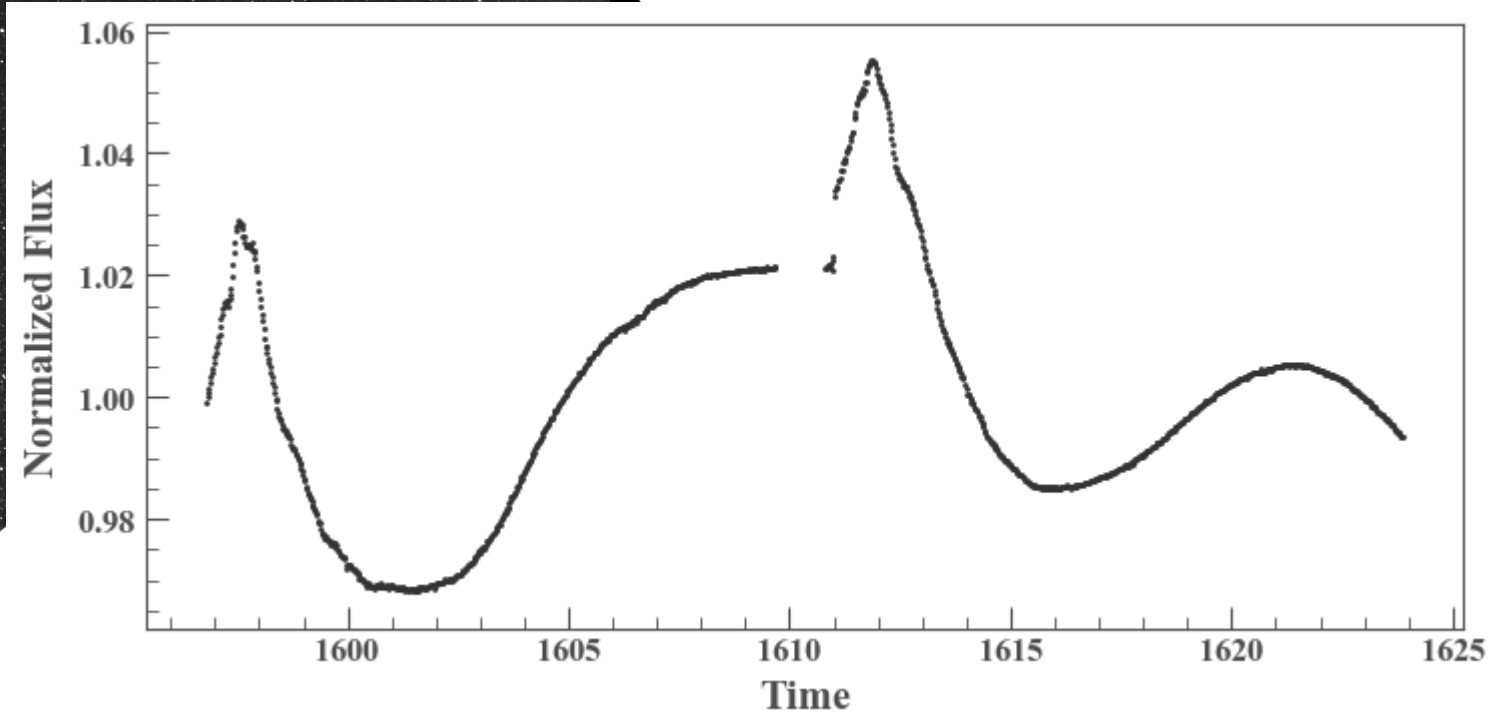


γ Cru (Gacrux)

M3.5III

Tmag = -1.04





In [1]:
```
import halophot
import numpy as np
from halophot.halo_tools import halo_tpf
```

In [2]:
```
fname = '../data/gamCru/tess-s0011-2-1_187.791498_-57.113213_25x25_astrocut.fits.gz'
tpf = halo_tpf(fname)
```

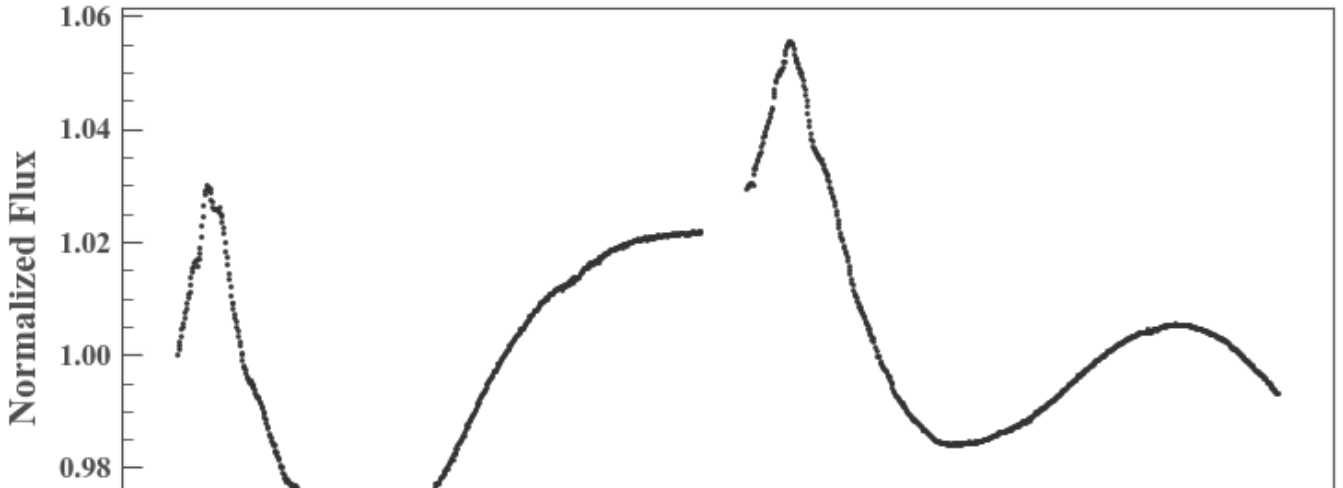
In [3]:
```
newmask = np.ones((tpf.flux.shape[1],tpf.flux.shape[2]),dtype='bool')
```

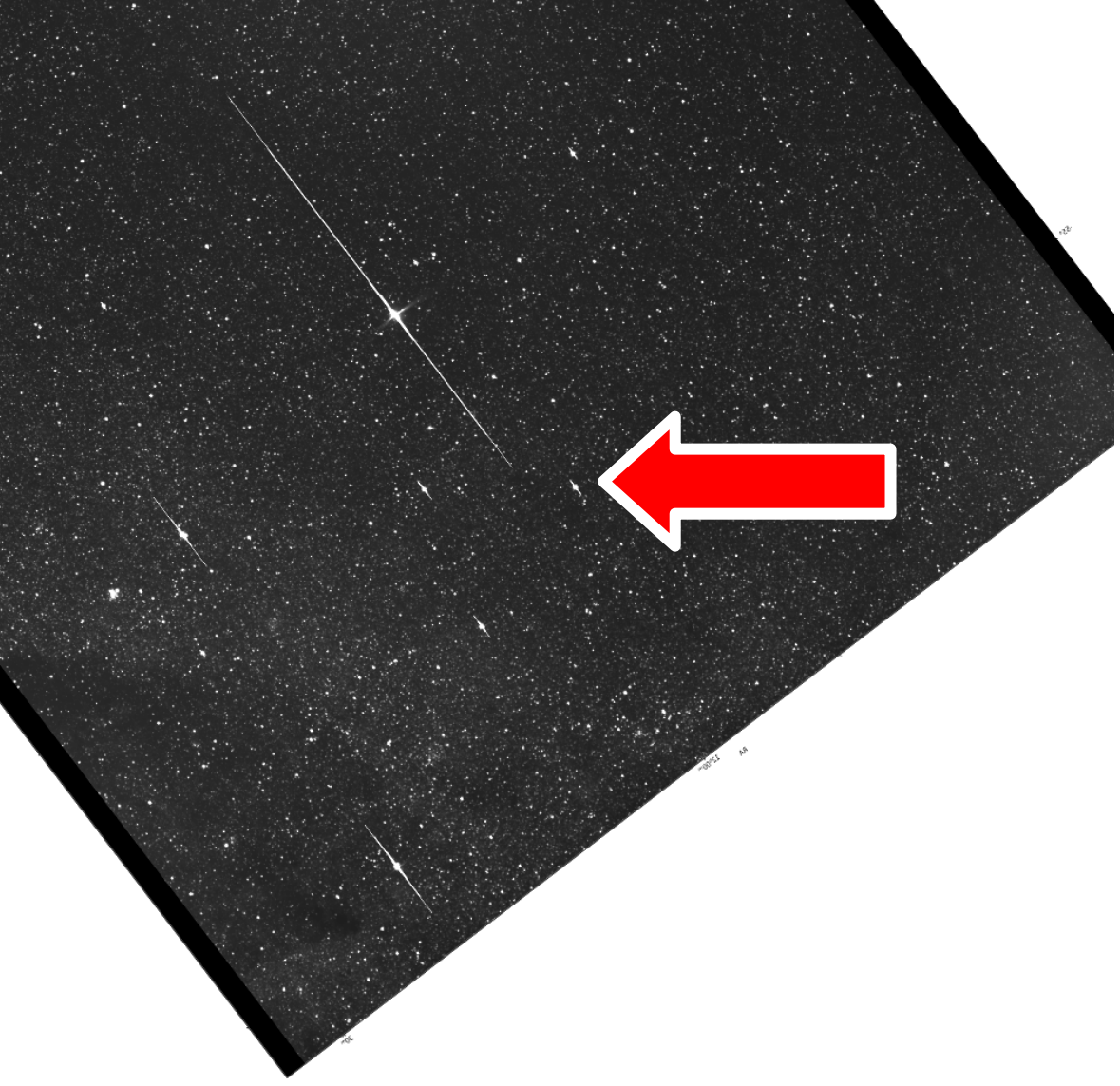
In [4]:
```
%%time
weightmap, corr_lc = tpf.halo(objective='tv',verbose=False,mask=newmask,minflux=-450,thresh=180,split_times=(1610.,))
```

```
CPU times: user 1.53 s, sys: 4.37 ms, total: 1.54 s
Wall time: 834 ms
```

In [5]:
```
corr_lc.scatter()
```

Out[5]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7f2fb17b3860>
```

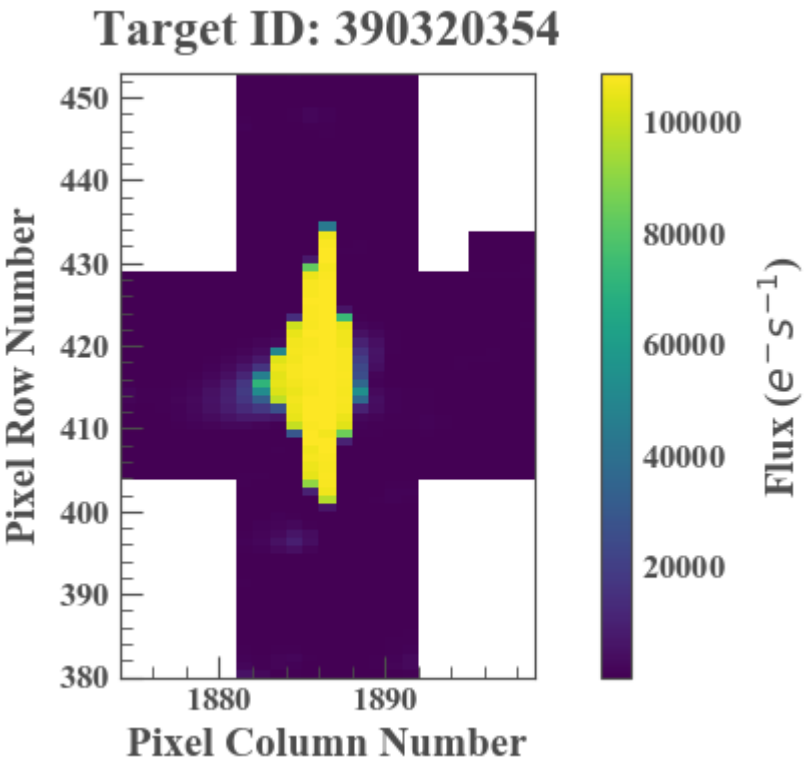




δ Cru (Imai)

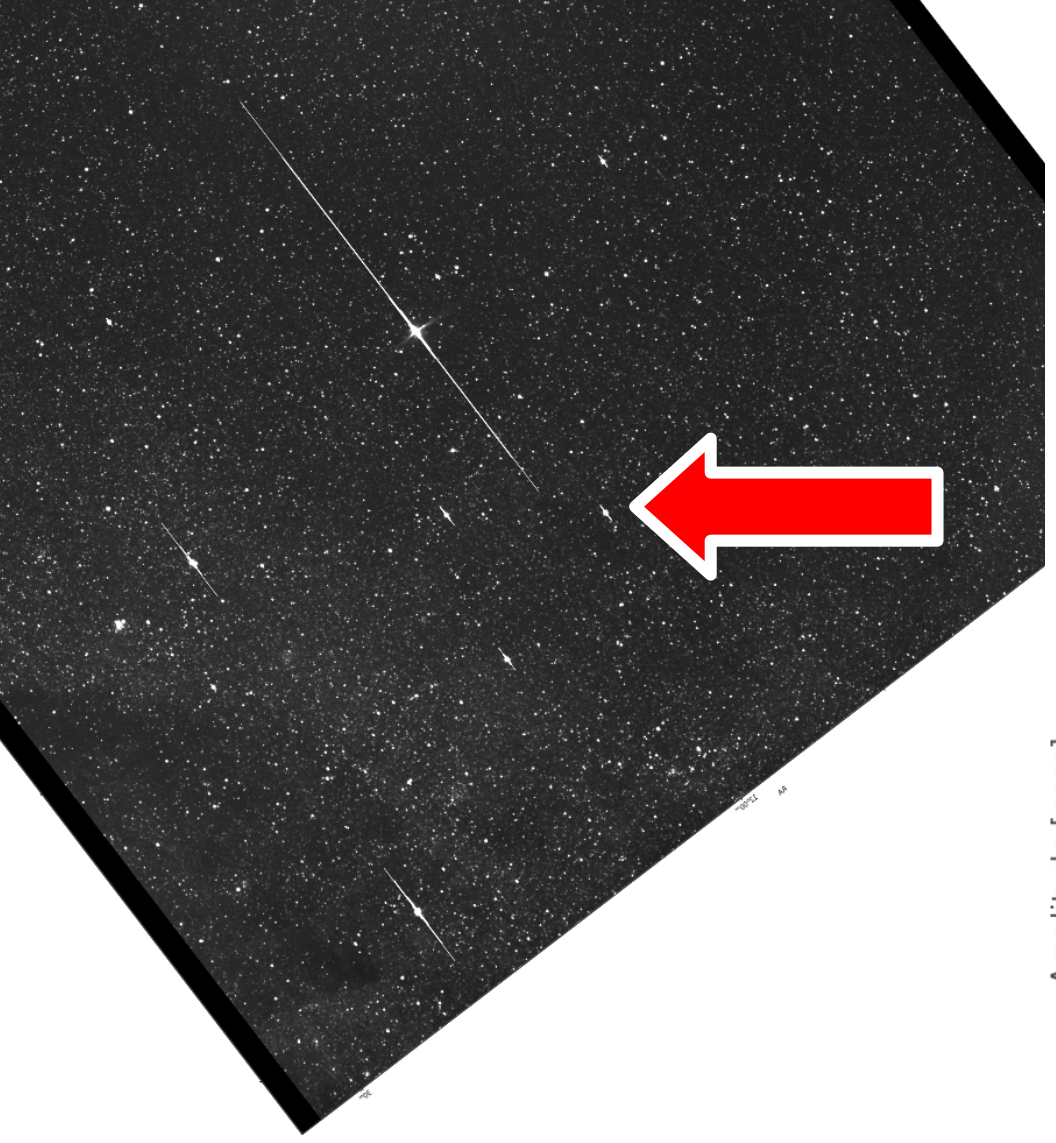
B2IV

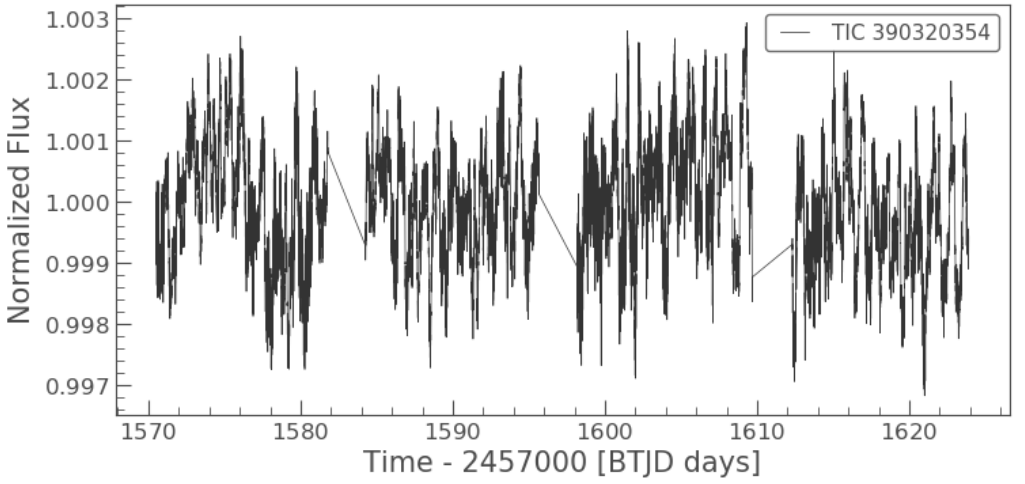
Tmag = 2.06

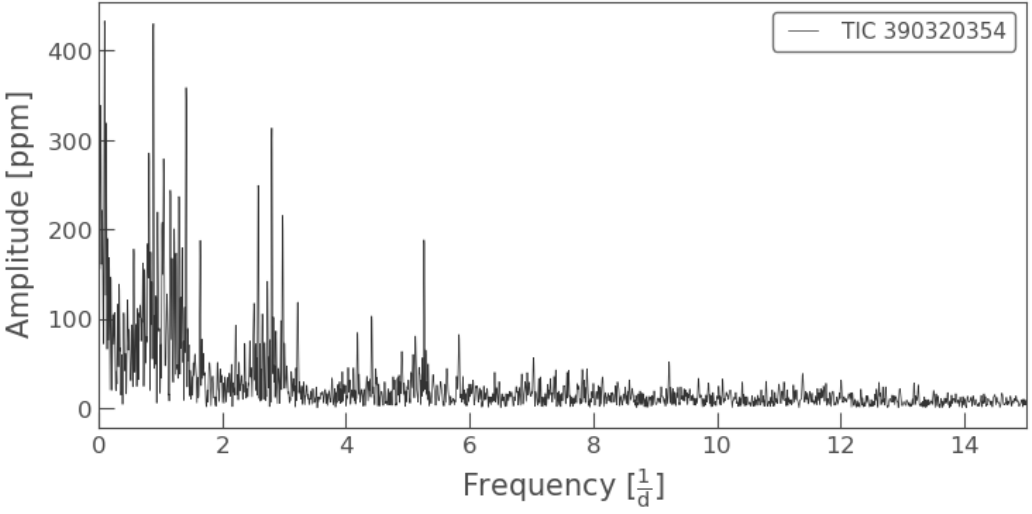


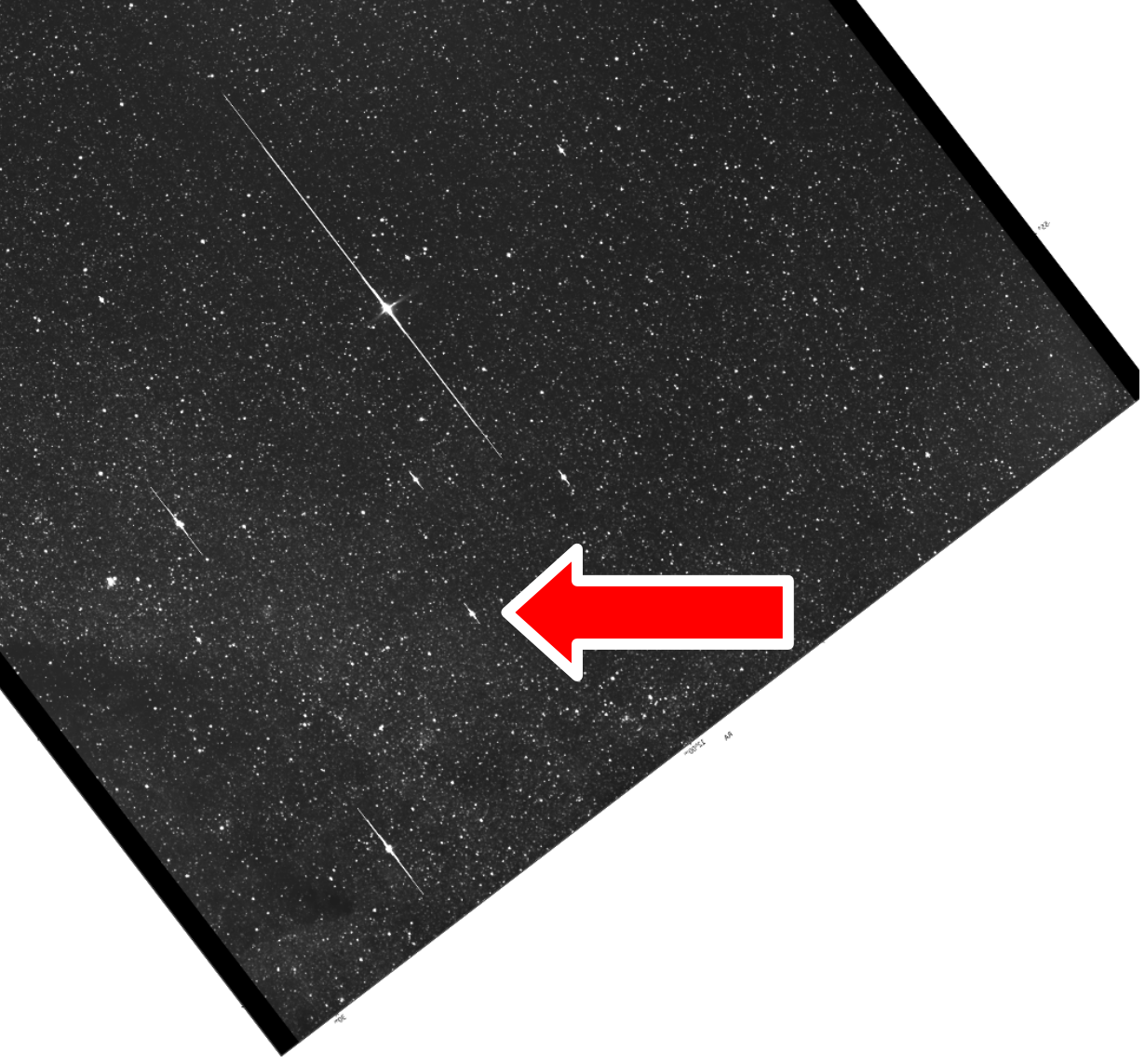
δ Cru (Imai)

B2IV





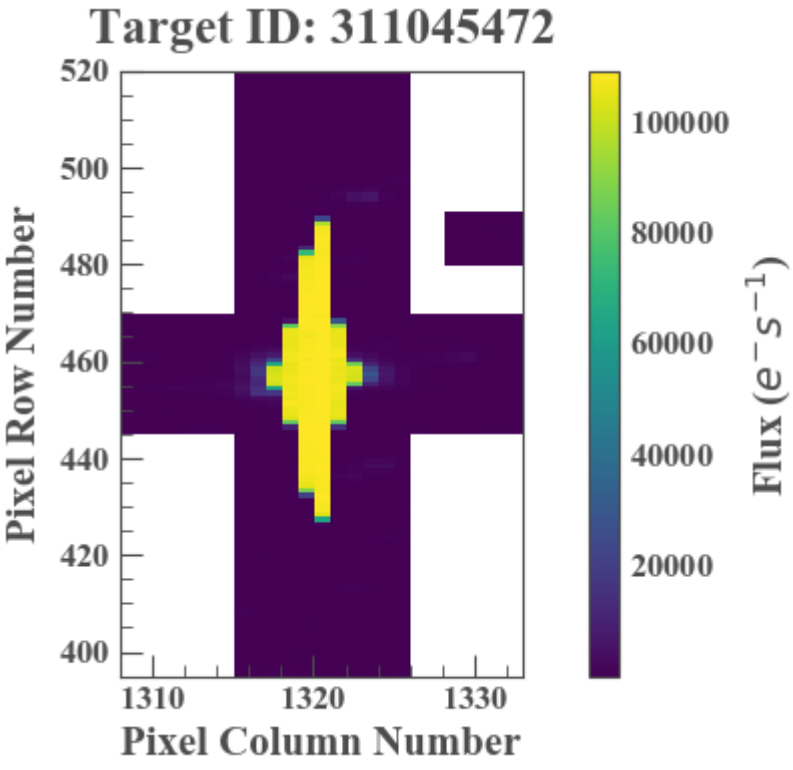




ε Cru (Ginan)

K3III

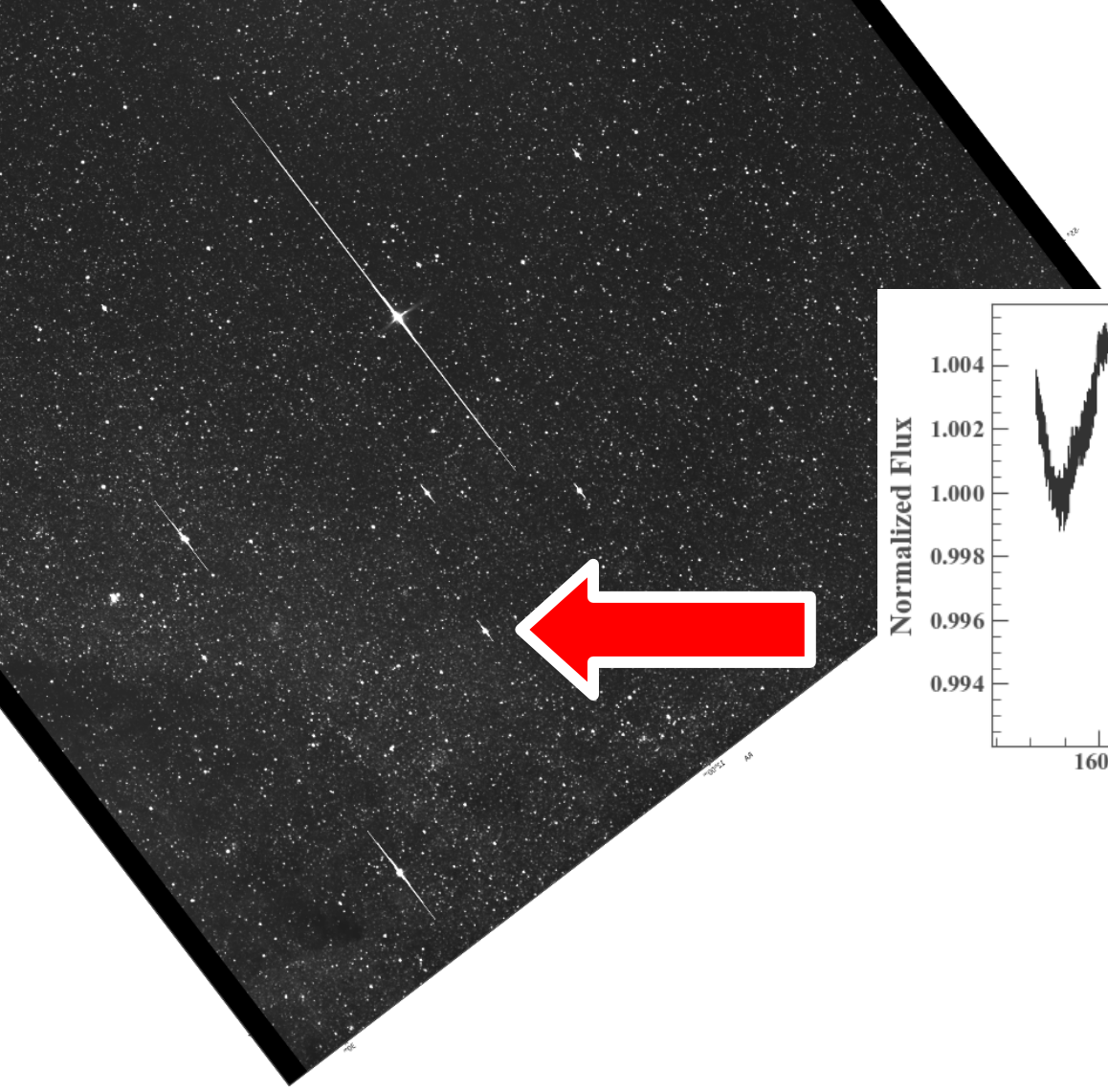
Tmag = 2.31

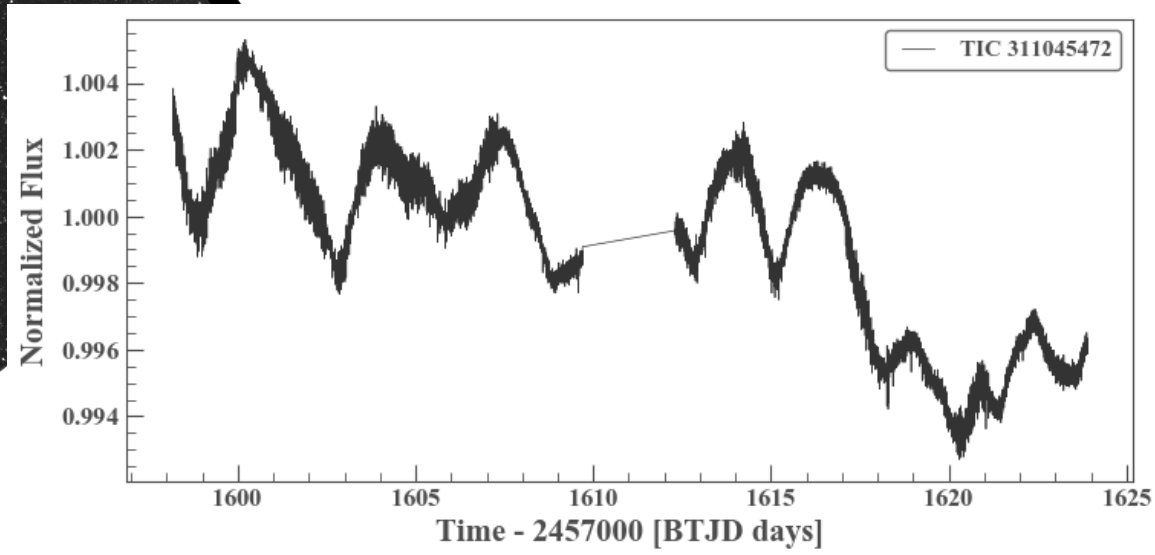


ε Cru (Ginan)

K3III

Tmag = 2.31





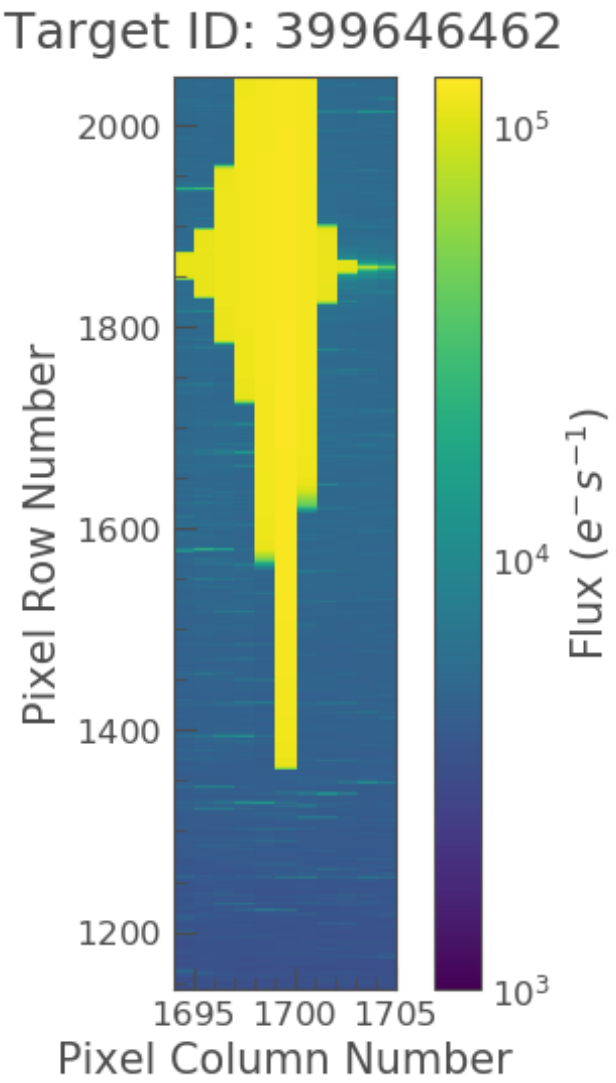
Summary

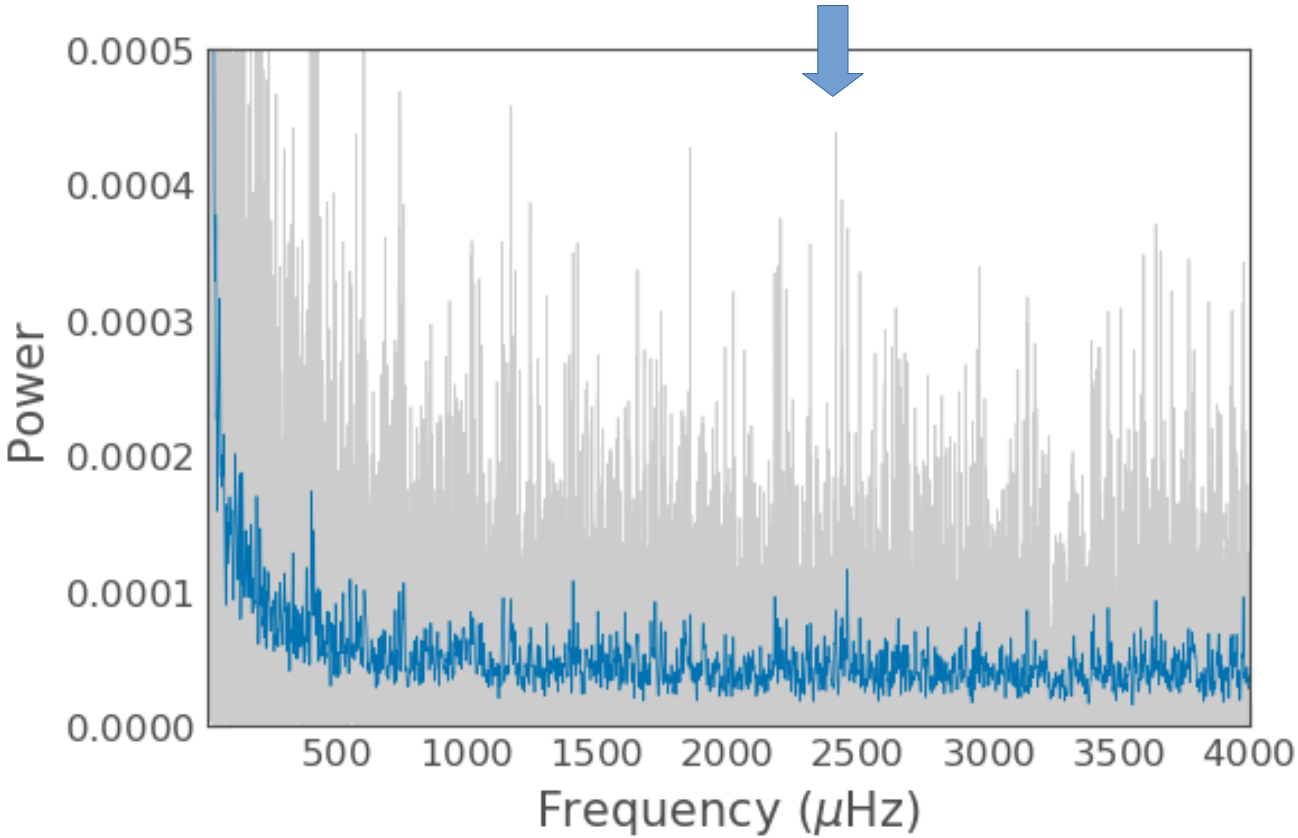
Bright stars present unique challenges including:

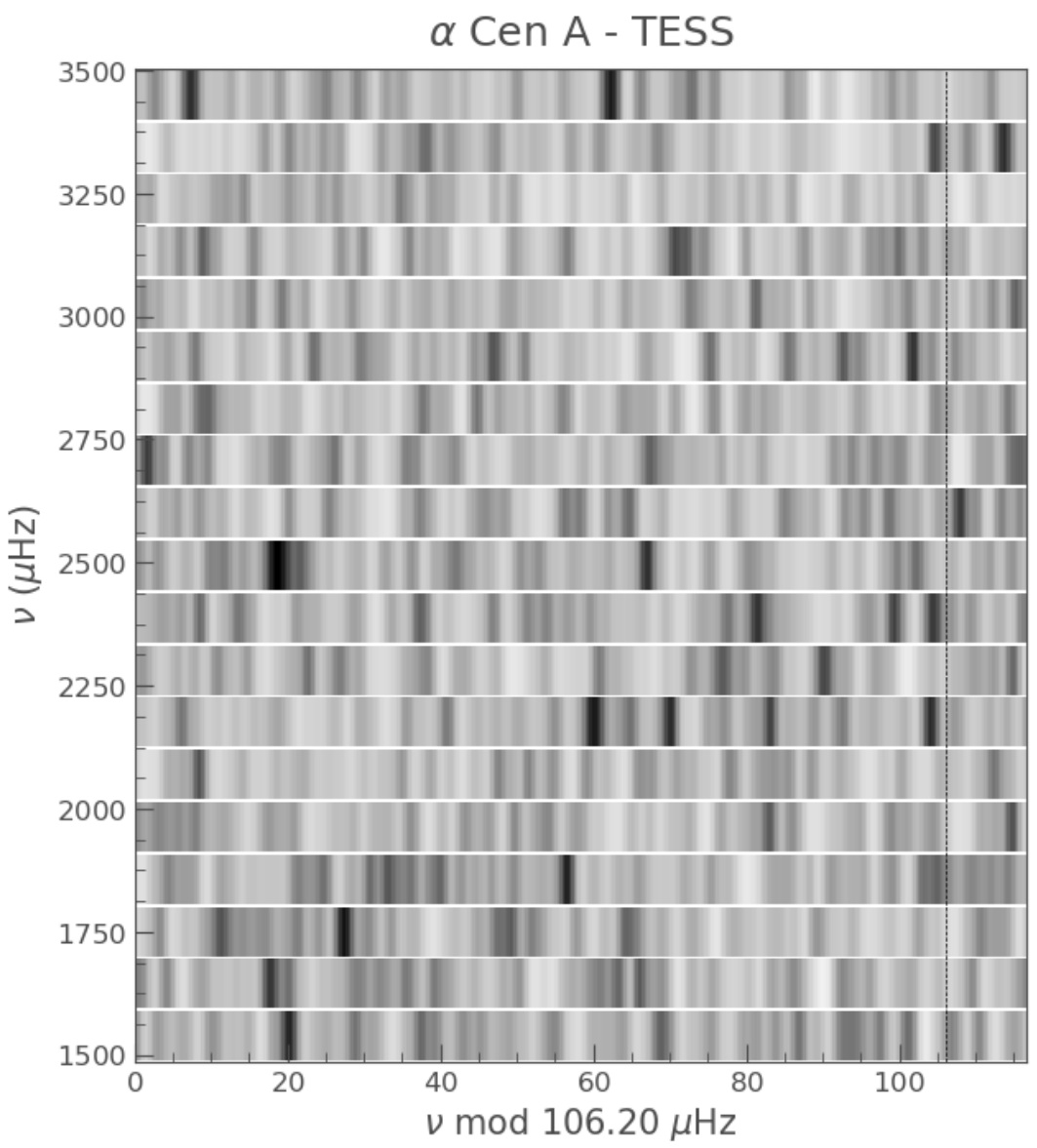
- Smear correction
- Backgrounds
- Aperture losses

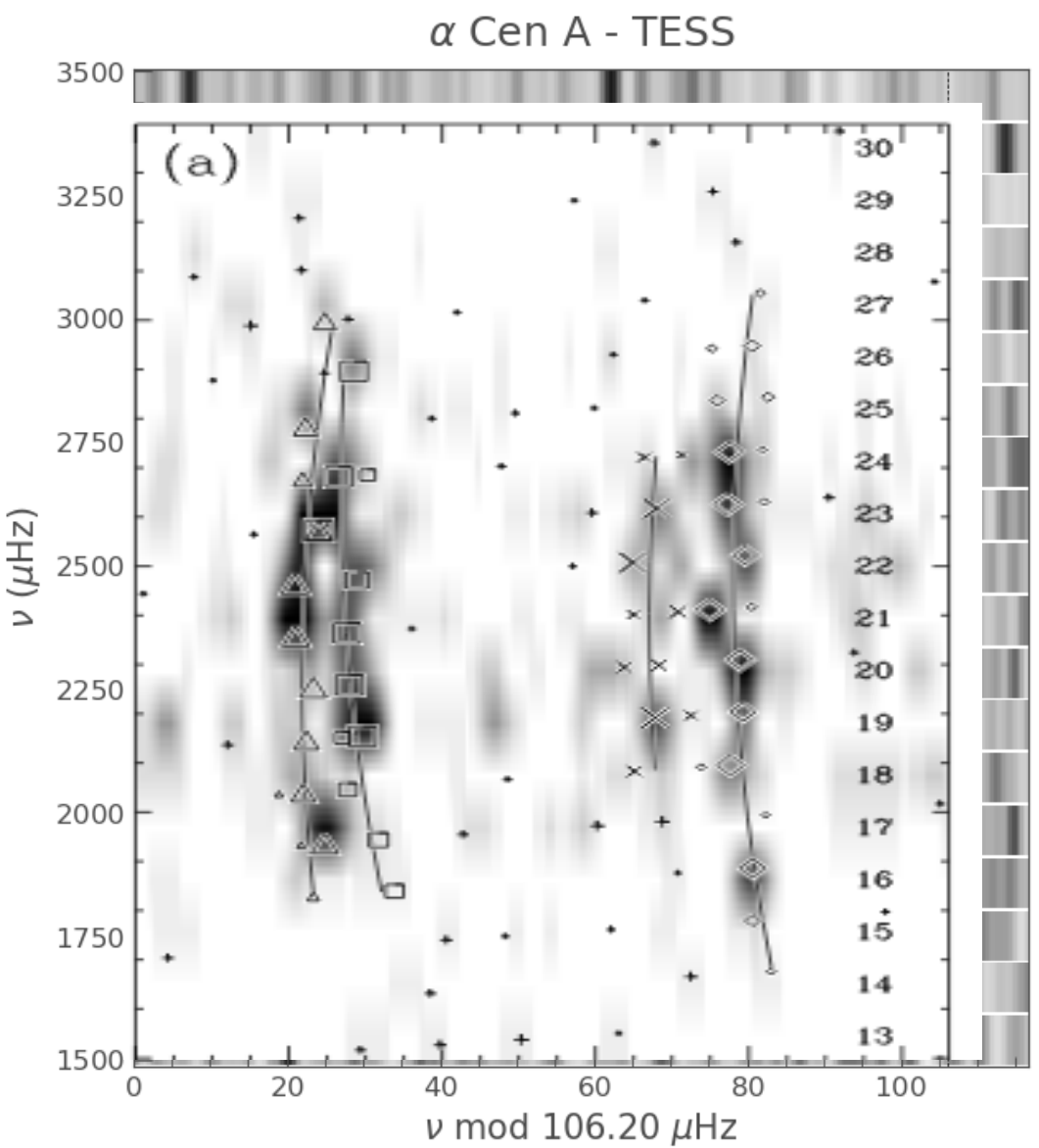
We’re overcoming these challenges in the TASOC pipeline to produce light curves of the brightest stars

α Centauri

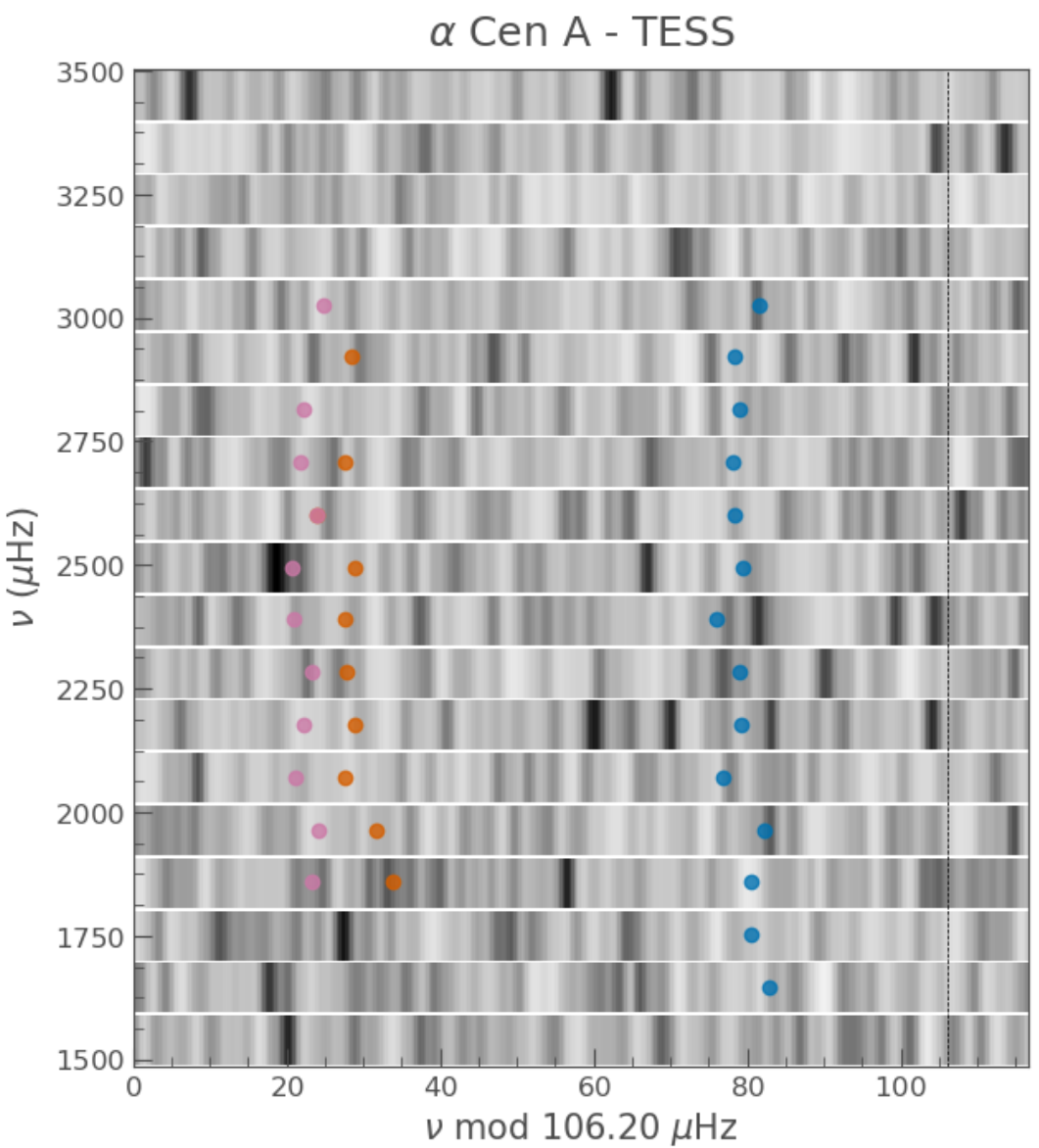

Target ID: 399646462
2000
1800
1600
1400
1200
Pixel Row Number
1695 1700 1705
Pixel Column Number
10^5
10^4
10^3
Flux (e^-s^{-1})


0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Power
500 1000 1500 2000 2500 3000 3500 4000
Frequency (μHz)


α Cen A - TESS
3500
3250
3000
2750
2500
2250
2000
1750
1500
ν (μHz)
0
20
40
60
80
100
ν mod 106.20 μHz

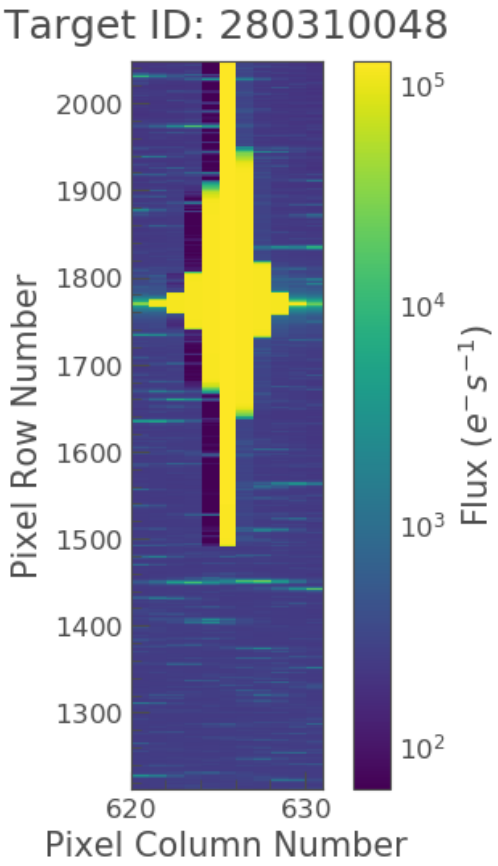


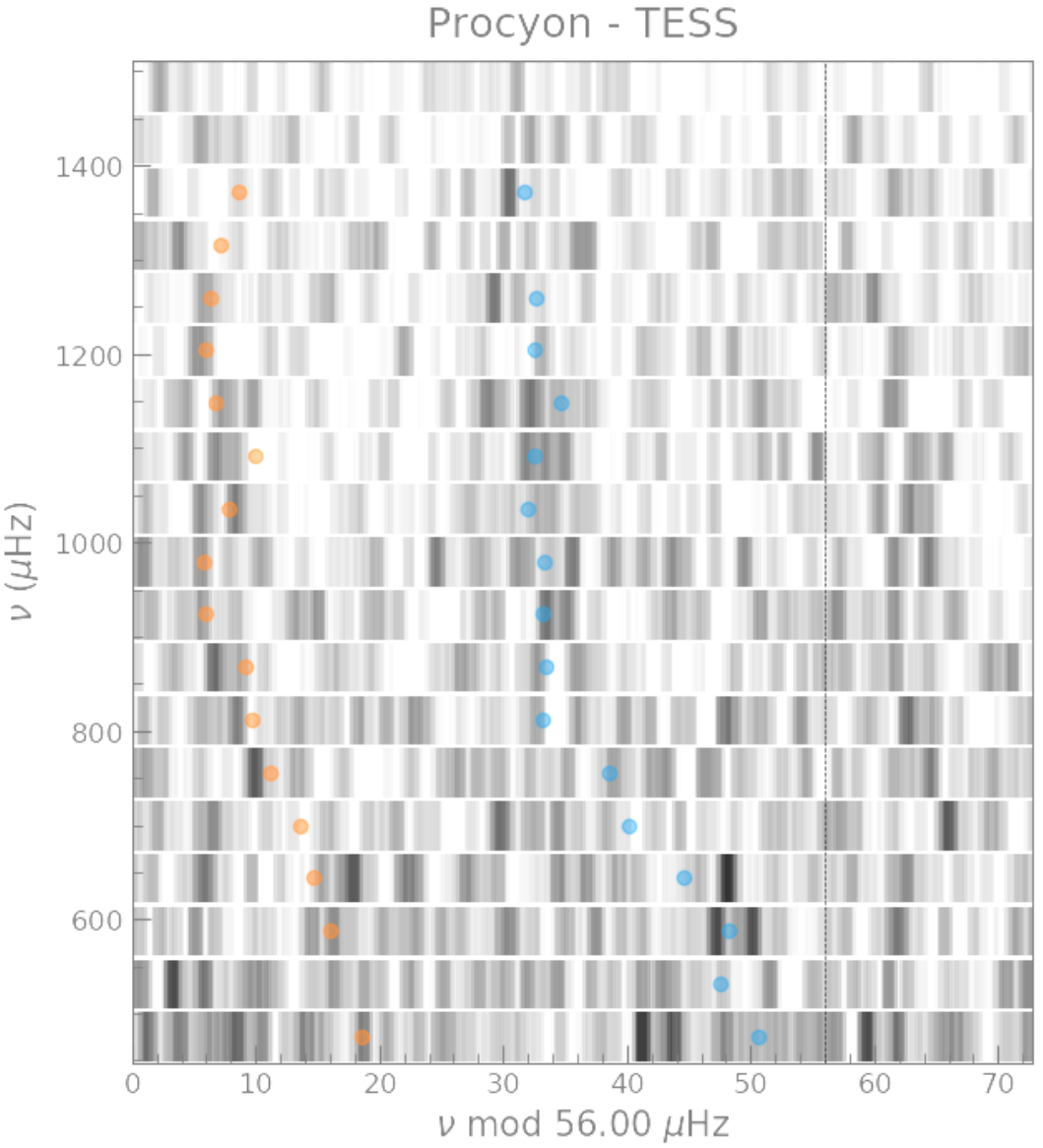
Bedding et al. 2004



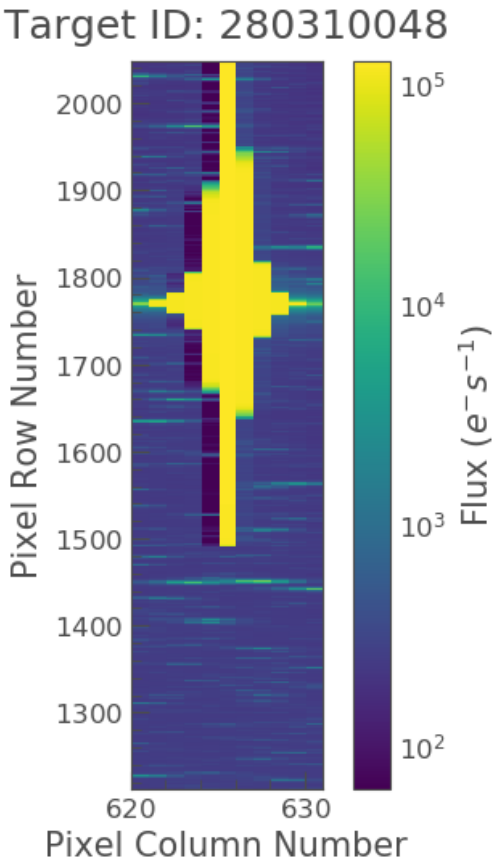
Frequencies from
Bedding et al. 2004

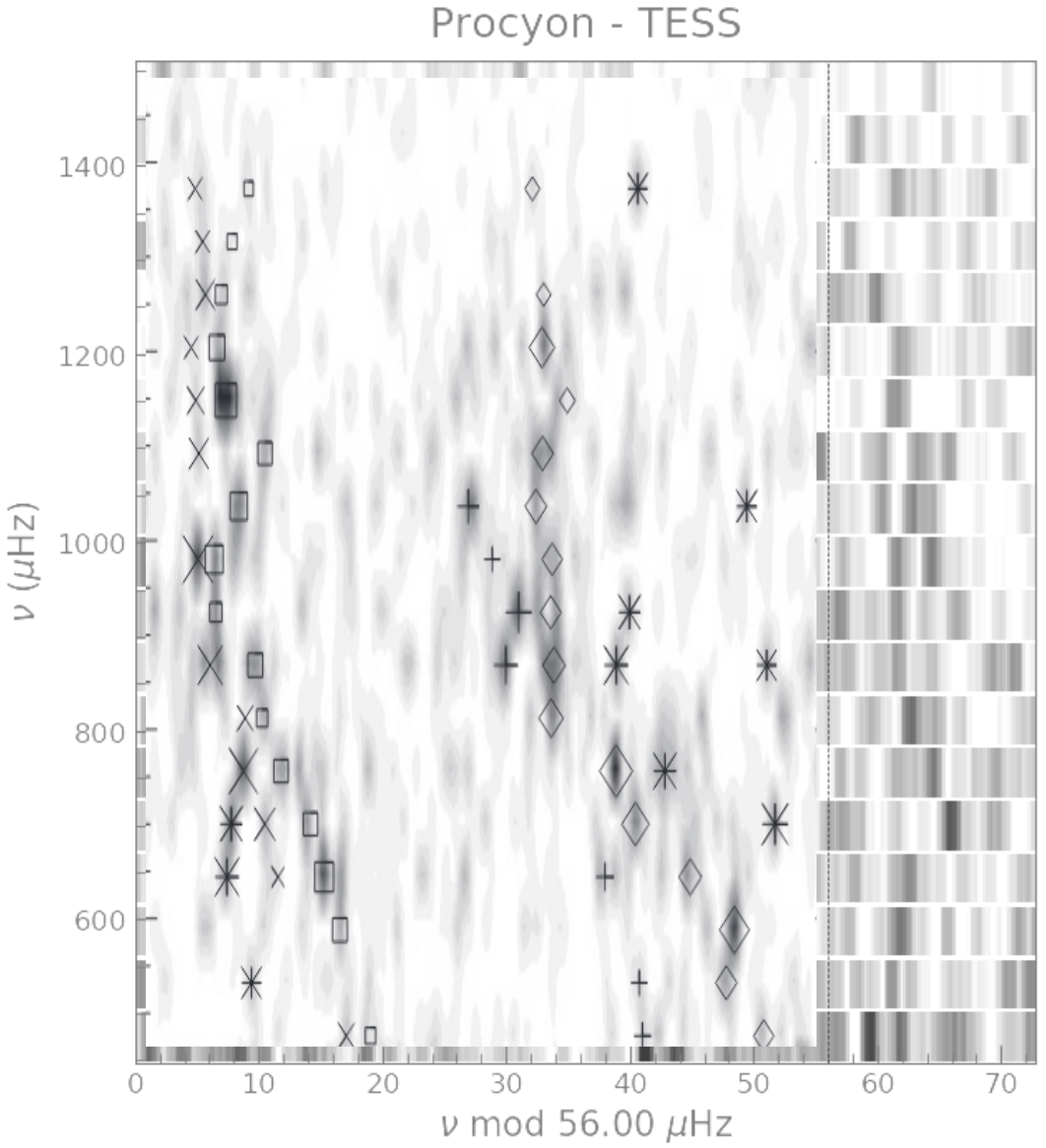
Procyon


Target ID: 280310048
Pixel Row Number
2000
1900
1800
1700
1600
1500
1400
1300
620
630
Pixel Column Number
10^5
10^4
10^3
10^2
Flux (e^-s^{-1})


Procyon - TESS
1400
1200
1000
800
600
ν (μHz)
0
10
20
30
40
50
60
70
ν mod 56.00 μHz

Procyon


Target ID: 280310048
Pixel Row Number
2000
1900
1800
1700
1600
1500
1400
1300
620
630
Pixel Column Number
10^5
10^4
10^3
10^2
Flux (e^-s^{-1})


Procyon - TESS
1400
1200
1000
800
600
ν (μHz)
0
10
20
30
40
50
60
70
ν mod 56.00 μHz