



The Detective's Guide to Stellar Variability: **Sinusoidal Signals Among O-F Main-Sequence Stars**

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Binary?



Motivation

Photometric variability in O-F stars can be explained with different mechanisms:

- **Binarity** (eclipsing binaries, spectroscopic binaries)
- **Pulsation**
- **Rotation** (spots on stellar surface)

This work aimed to identify and classify sinusoidal variables and reveal the origin of variations

Heavily relied on photometric and spectroscopic data reduction and analysis.

Ellipsoidal variables

- Close binary systems
- Stars deformed into ellipsoid shape
- During orbit components are seen from different angles - flux change

Pulsating stars

- Stars contract and expand
- Radial or non-radial pulsations
- Stars change temperature and therefore their brightness

Spots

- Elements elevated onto surface layers and frozen by magnetic field
- Spots are stable on surface
- Spots redistribute radiation

Data Sources



+ Catalog Data

The Transiting Exoplanet Survey Satellite (TESS)

Location: Orbit of 13.7 d around the Earth



Echelle spectrograph OES

Location: Ondřejov, Czech Republic



Echelle spectrograph MUSICOS

Location: Skalnaté Pleso, Slovakia



Echelle spectrograph PUCHEROS+

Location: La Silla, Chile



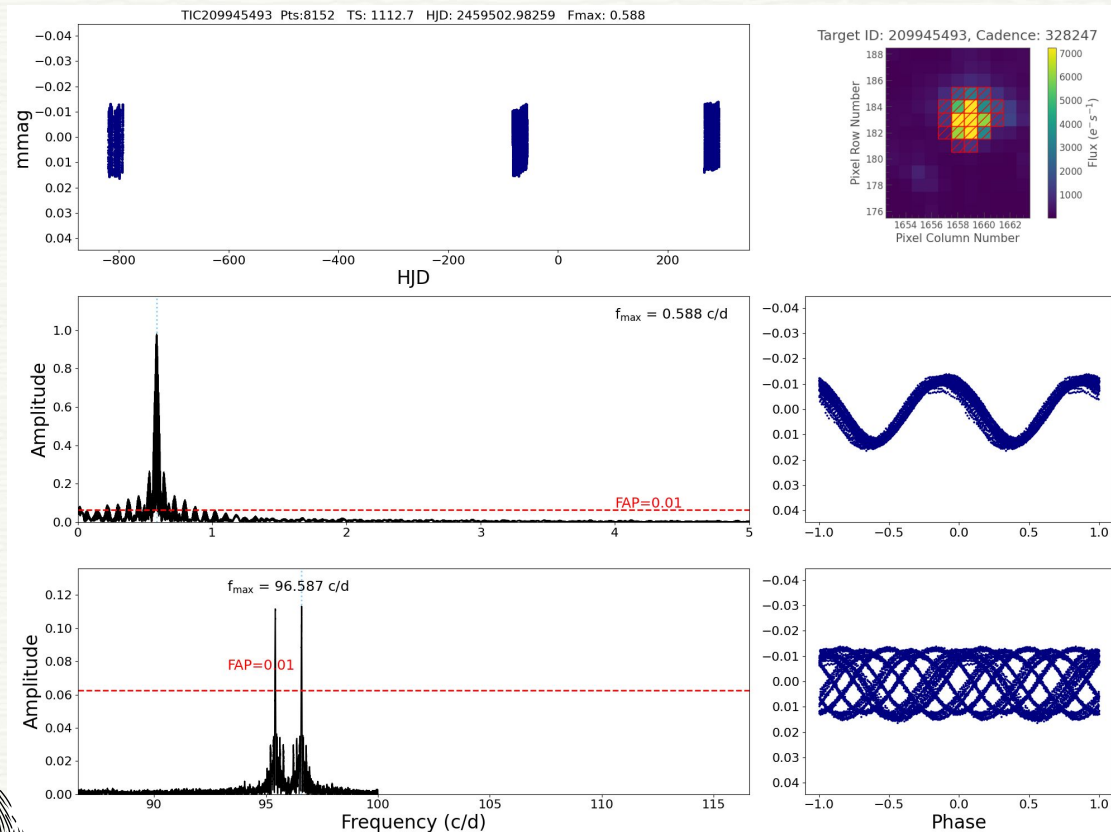
Initial Sample

TIC Catalog

Criteria:

- Temperature above 6500 K
- Stars brighter than 9 mag

45780 objects



Initial Sample

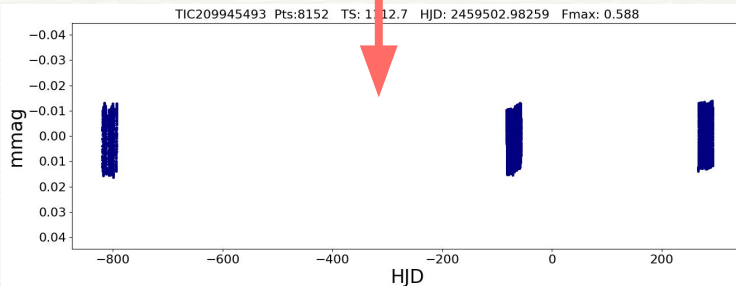
TIC Catalog

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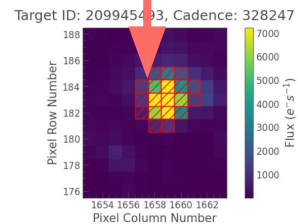
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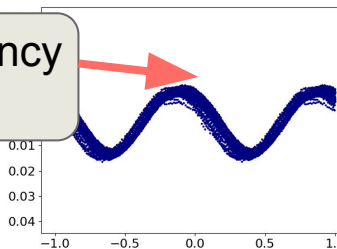
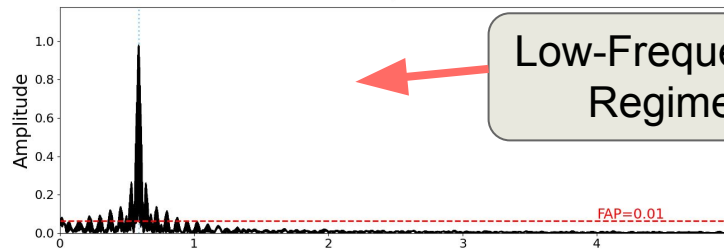
Light Curve



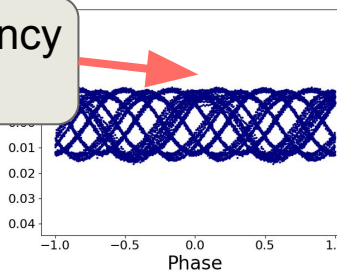
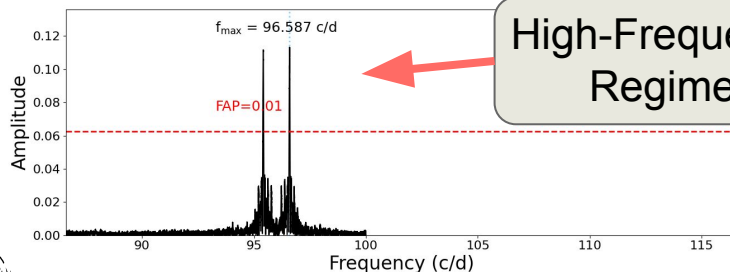
Star Background



Low-Frequency Regime



High-Frequency Regime



Sample Candidates

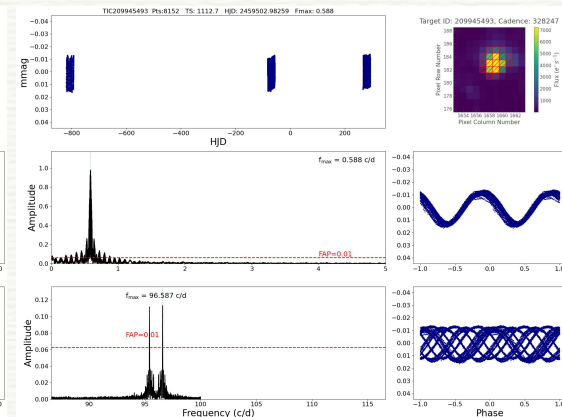
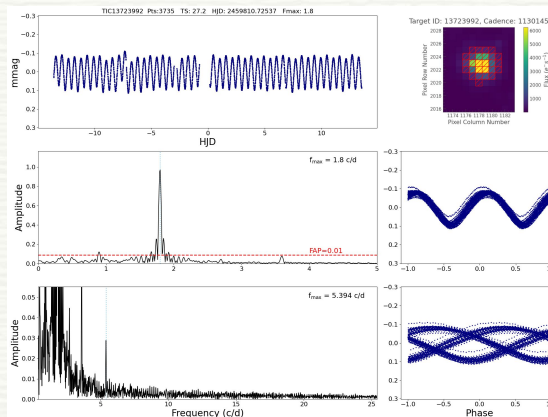
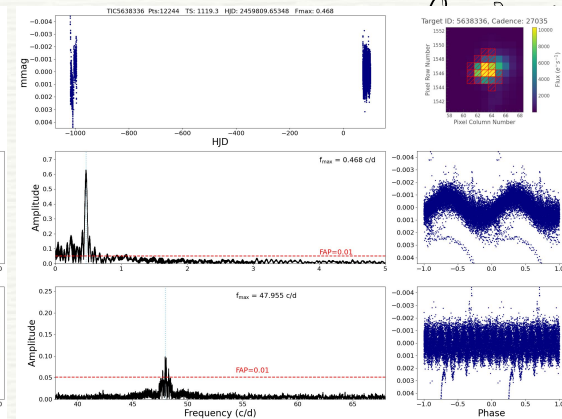
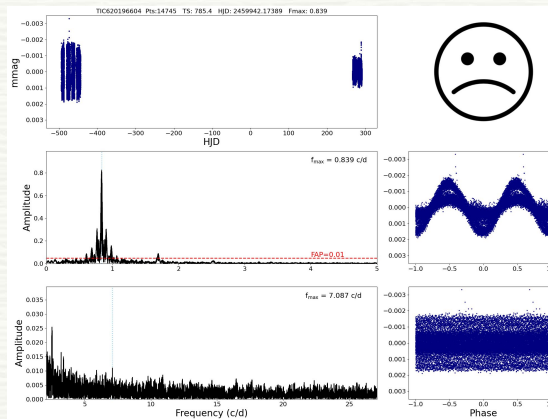
45780 objects

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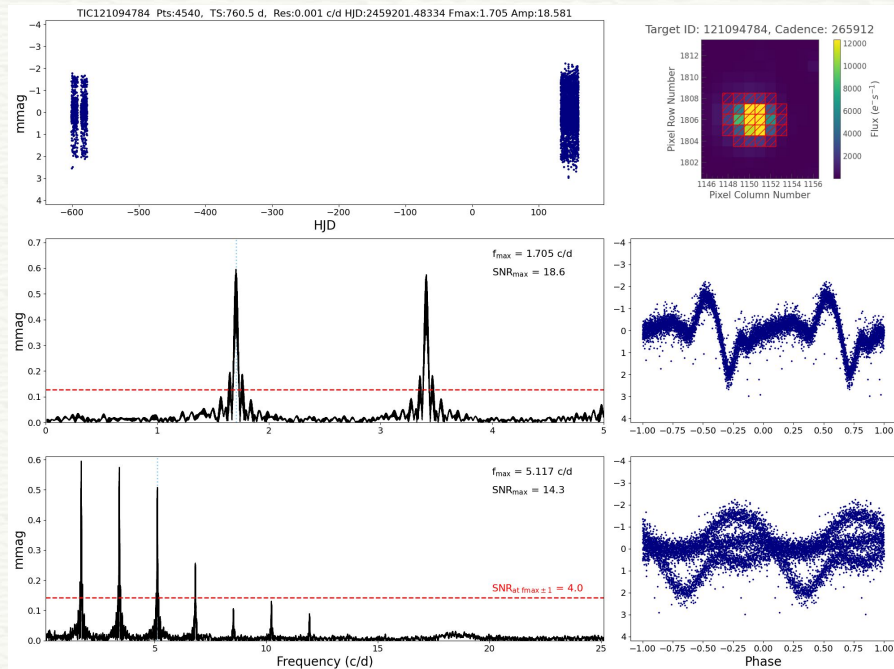
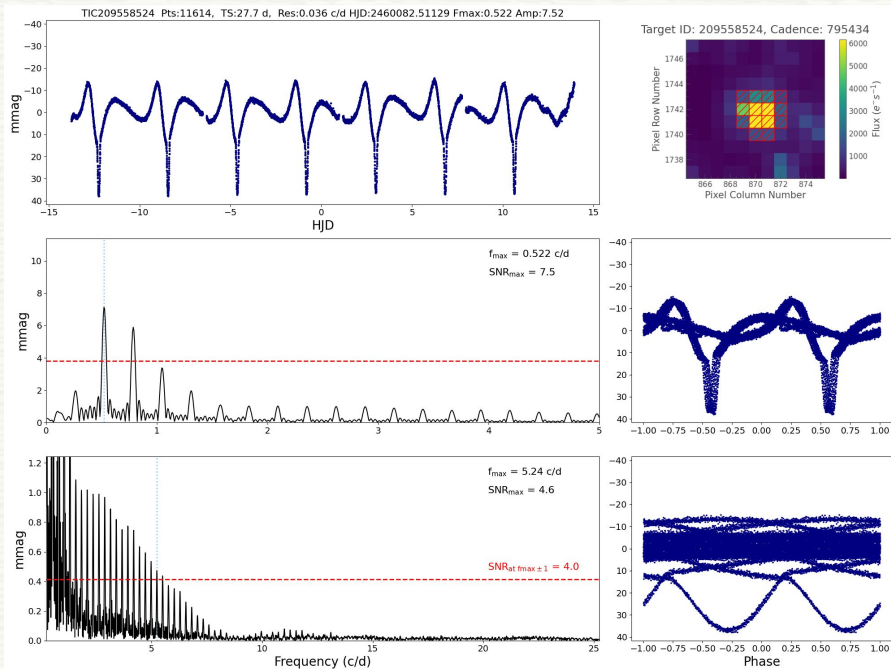
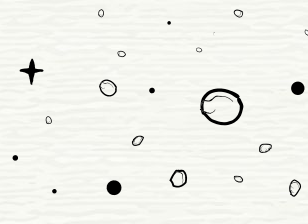
- Sinusoid in low-freq regime
- We did not consider variations in high-freq regime
- Not a blend

472 objects

These objects were subjected to additional processing



Interesting Objects



Heart-beat Stars

Sample Candidates

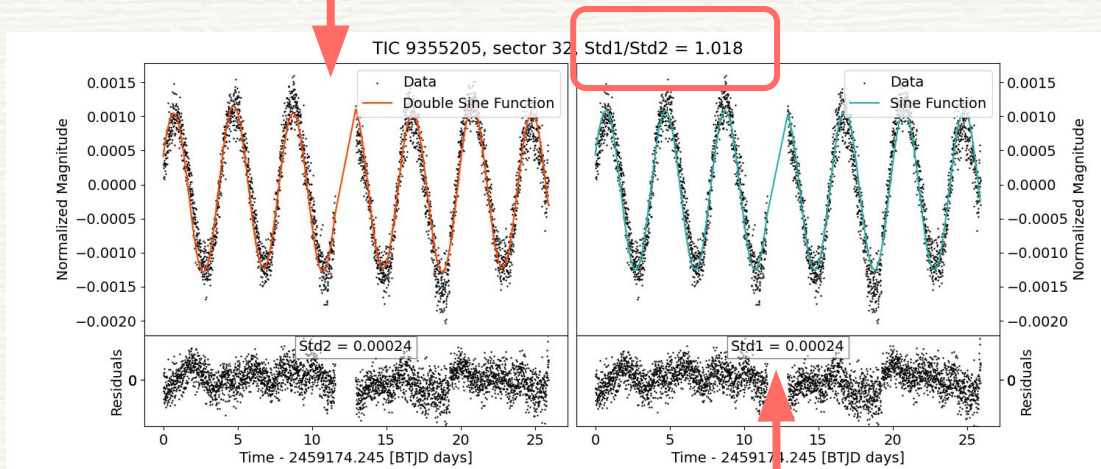
472 objects

Criteria:

- Residua ratio below 1.1
- No pulsational modulation
- No change in period or shape

108 objects

$$y = a_1 \sin(2\pi ft + \phi_1) + a_2 \sin(\pi ft + \phi_2)$$



$$y = a_1 \sin(2\pi ft + \phi_1)$$

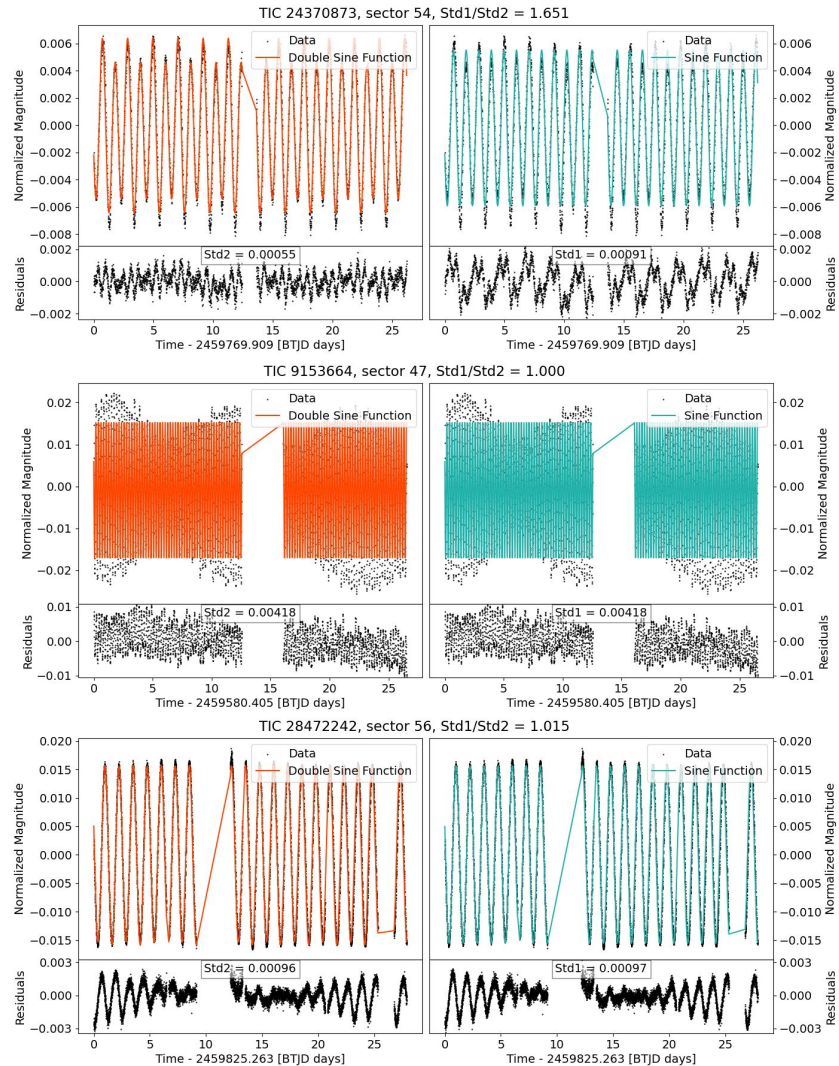
Sample Candidates

472 objects

Criteria:

- Residua ratio below 1.1 (a)
- No pulsational modulation (b)
- No change in period or shape (c)

108 objects



a

b

c

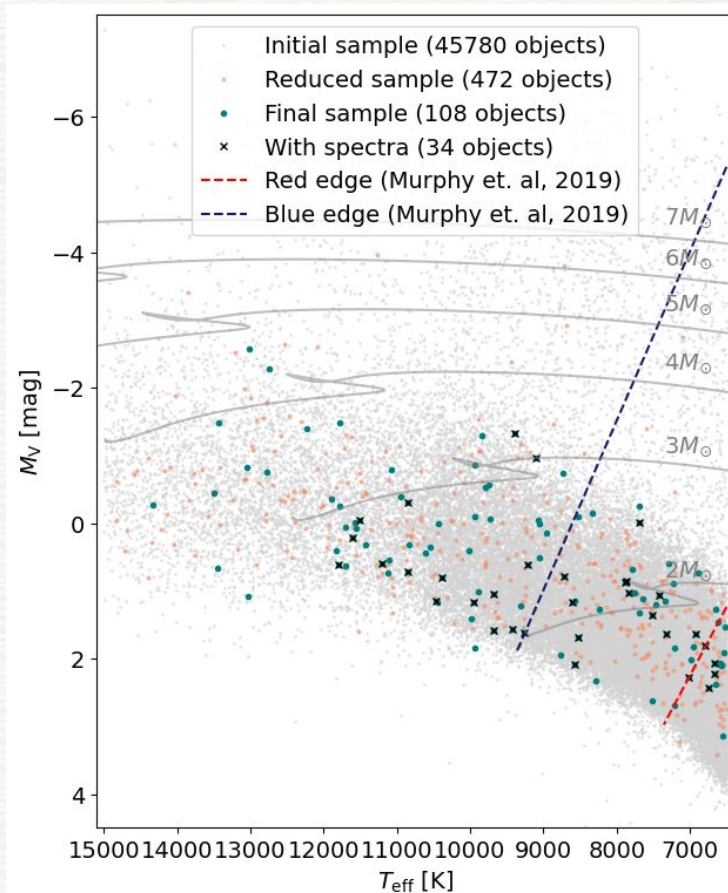
Spectroscopic Follow-up

108 objects

IRAF radial velocity
extraction

22 objects - south
12 objects - north

Observations with PUCHEROS+
ended in November 2024. OES
and MUSICOS provided data until
March 2025



Spectroscopic Follow-up

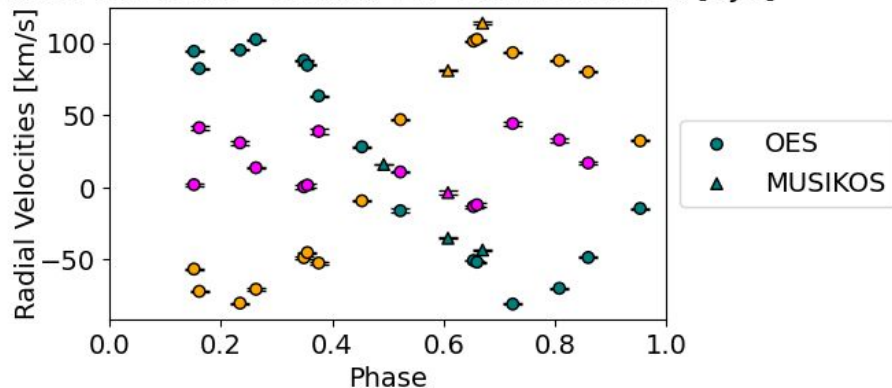
108 objects

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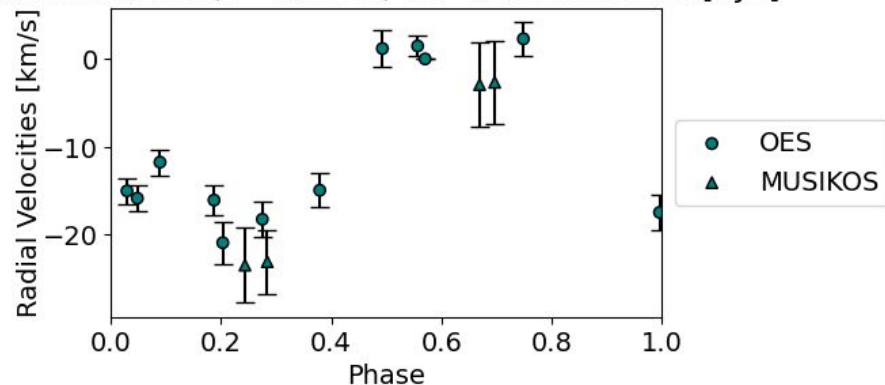
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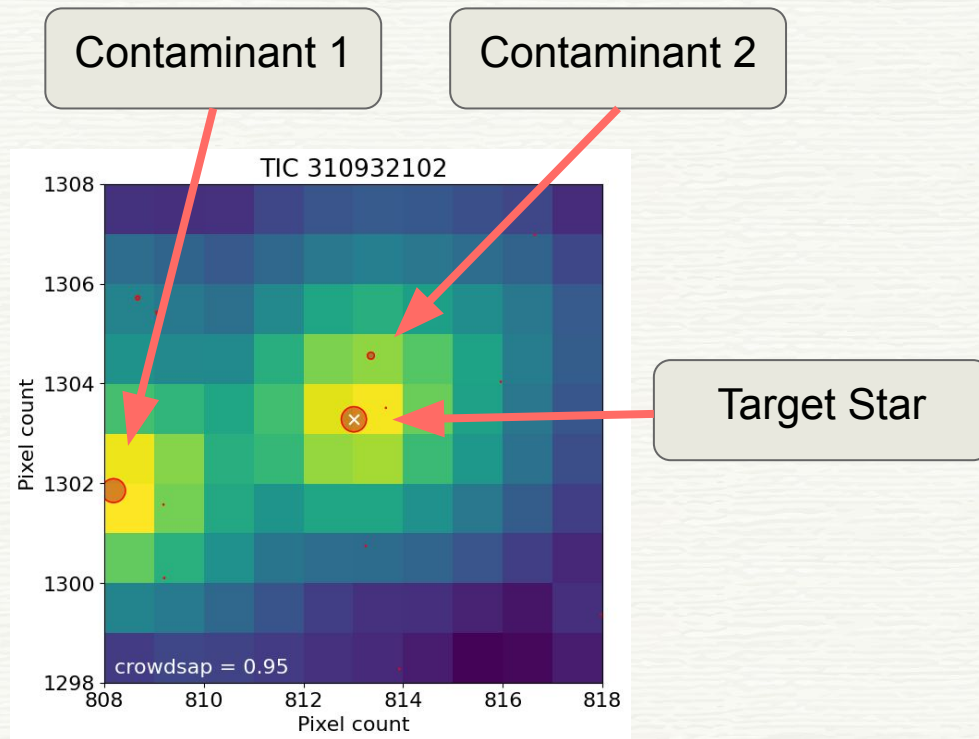
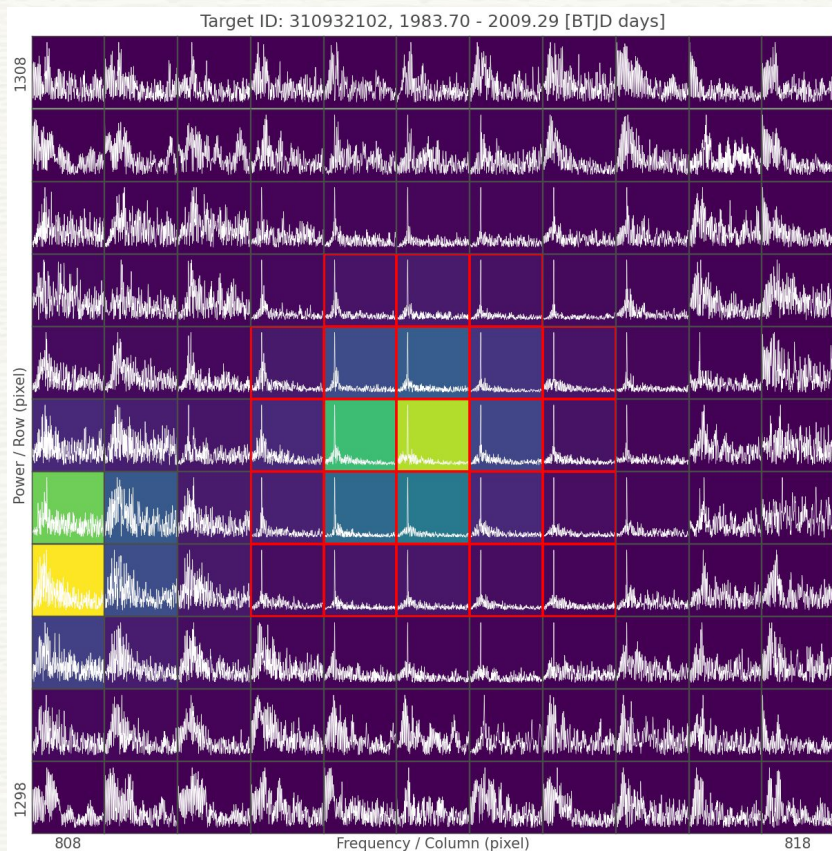
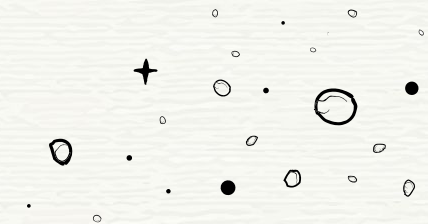
TIC14400891, $P=4.597\text{d}$, $M_0=2459583.843\text{d}$ [HJD]



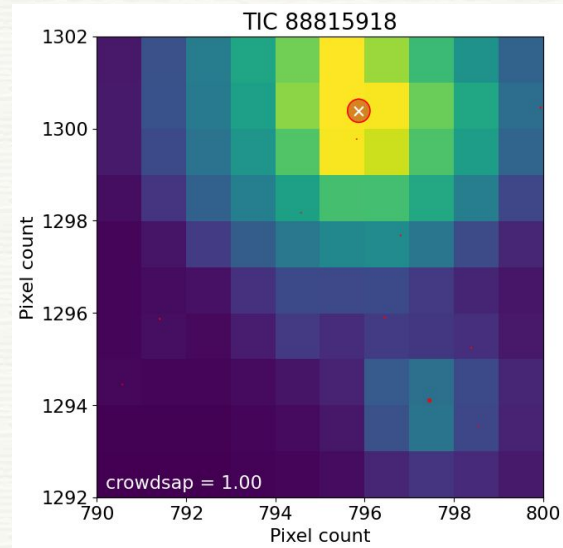
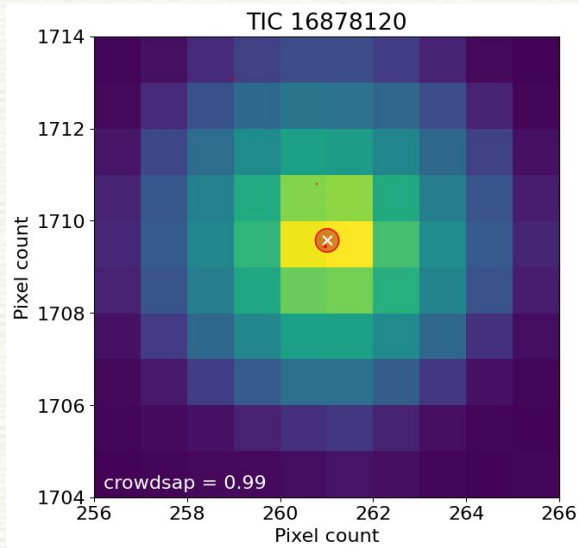
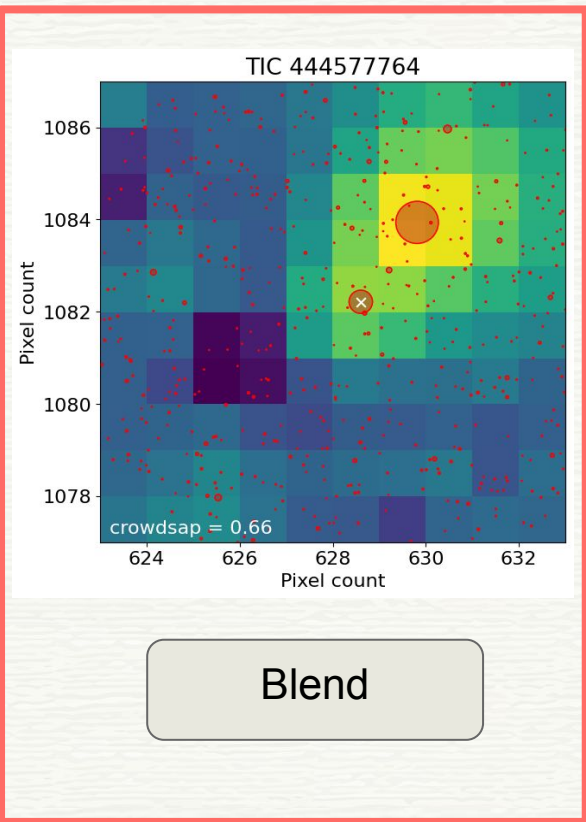
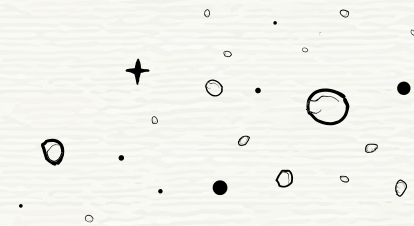
TIC302581695, $P=2.026\text{d}$, $M_0=2458875.219\text{d}$ [HJD]



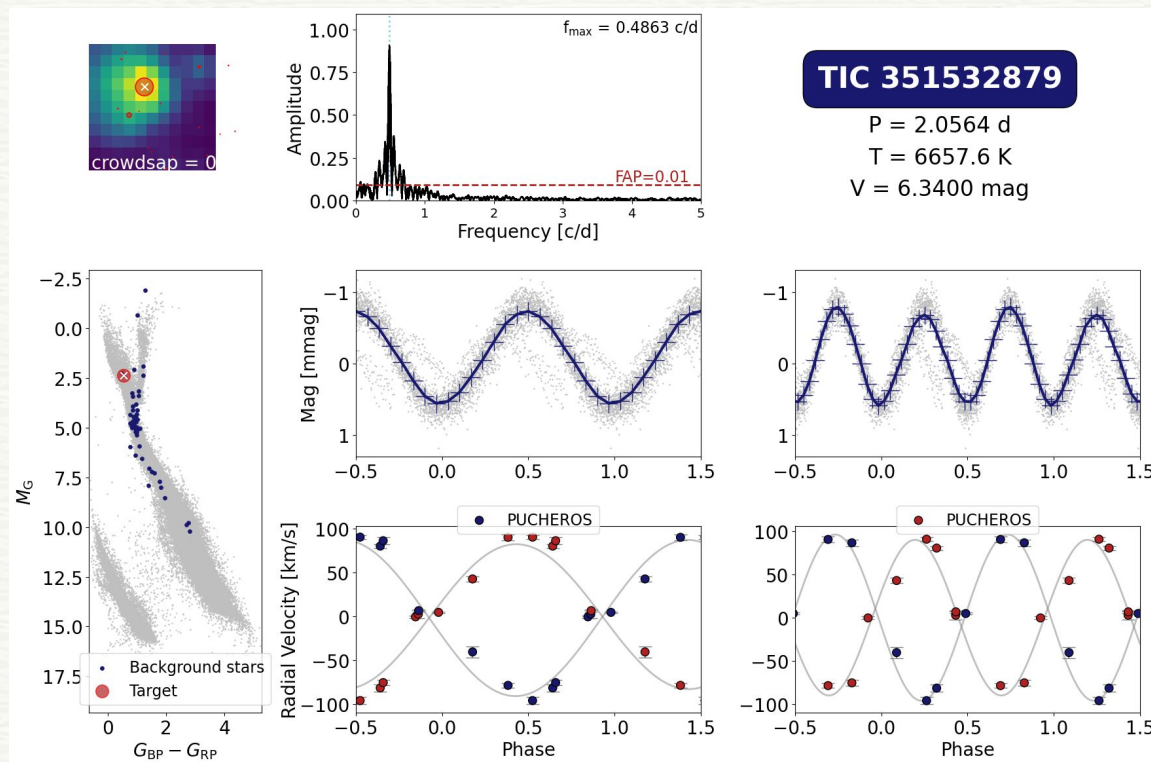
Background Analysis



Background Analysis



Classification

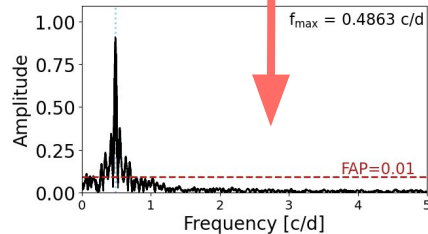
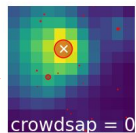


Like fingerprints reveal the identity of a person, the photometric and spectroscopic data help reveal the origin or variations

Classification

Frequency Spectra

Star Background

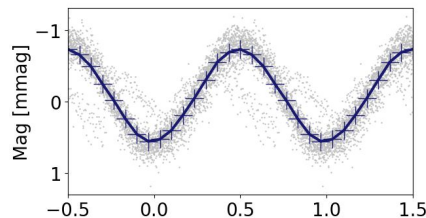
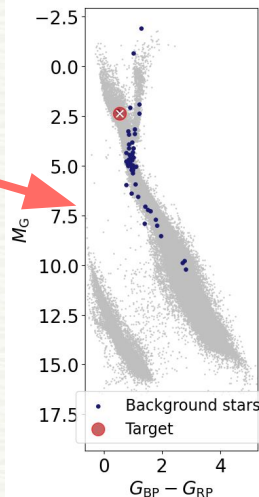


TIC 351532879

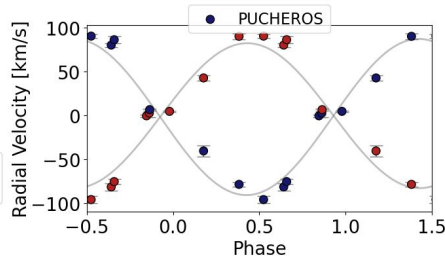
$P = 2.0564 \text{ d}$
 $T = 6657.6 \text{ K}$
 $V = 6.3400 \text{ mag}$

Information about
the object

Gaia HRD



Phased photometric
curve



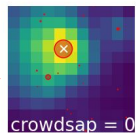
Phased radial
velocity curve



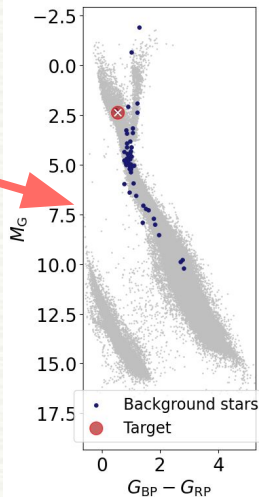
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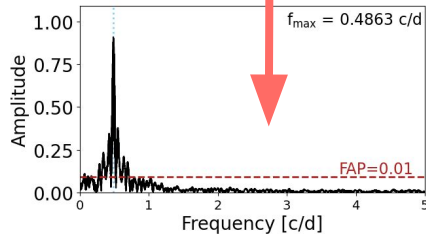
Star Background



Gaia HRD



Frequency Spectra

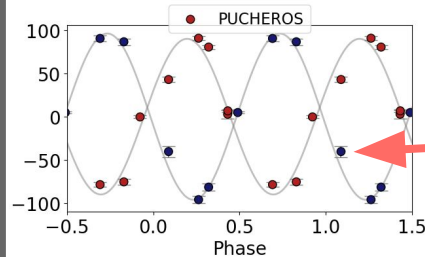
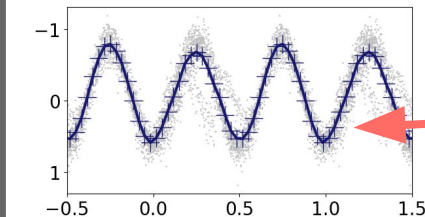
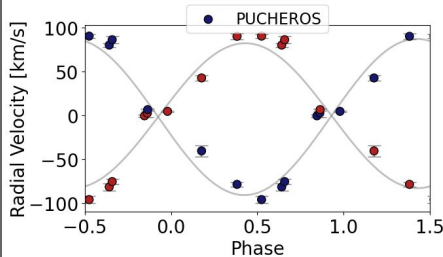
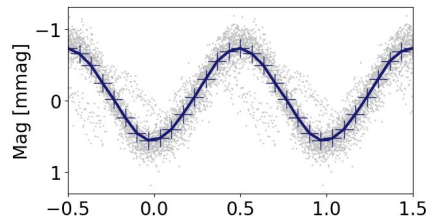


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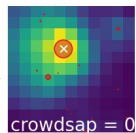
Phased with P

Phased with 2P

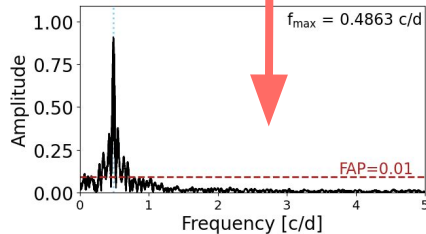
Classification

- Binary stars
- Pulsating stars
- Candidates for spots
- Uncertain objects

Star Background



Frequency Spectra

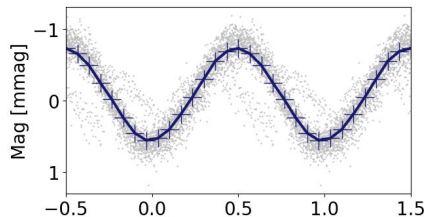
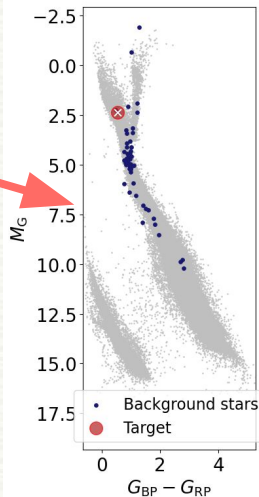


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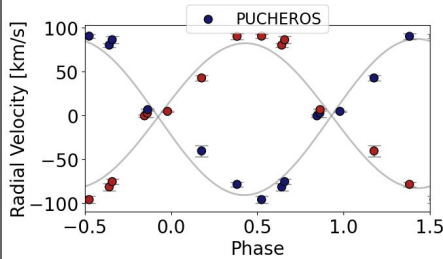
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Gaia HRD



Phased photometric
curve



Phased radial
velocity curve

Phased with P

Phased with 2P

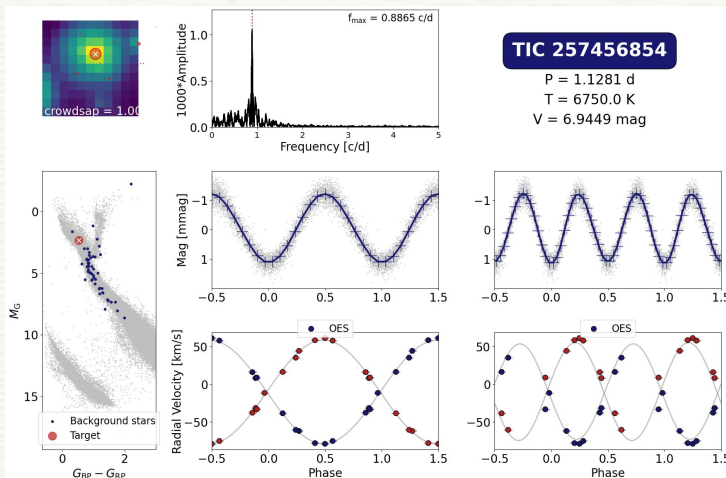
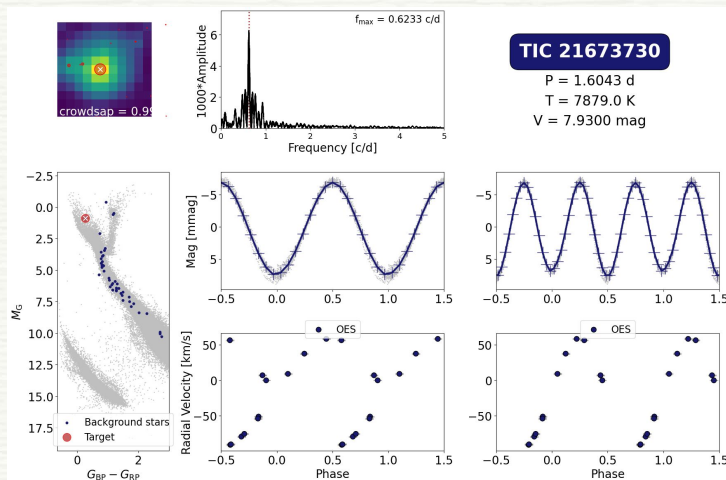
Classification

Binary stars

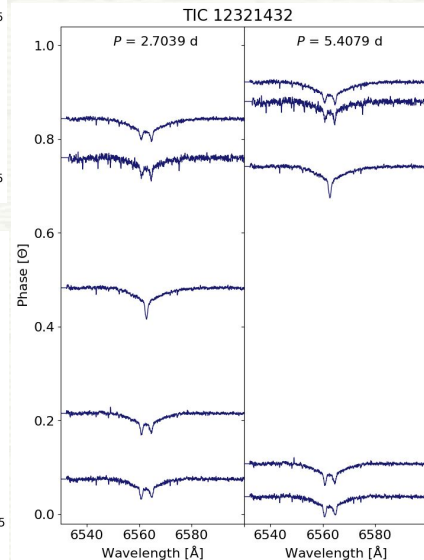
Variability in the **radial velocity curve**
phased with 2P

Three ways of picking out binary stars
from the stars of other classifications:

- **the spectral lines of both components are visible** - two separate radial velocity curves in antiphase
- **clear monotonic variation** when phased with twice the dominant period
- **lines of both components visible in spectra** (even if not visible in radial velocity curves)



- **Binary stars**
- **Pulsating stars**
- **Candidates for spots**
- **Uncertain objects**



Classification

Pulsating stars

The light curve and radial velocity curve are offset by a **phase difference of $\pi/2$** .

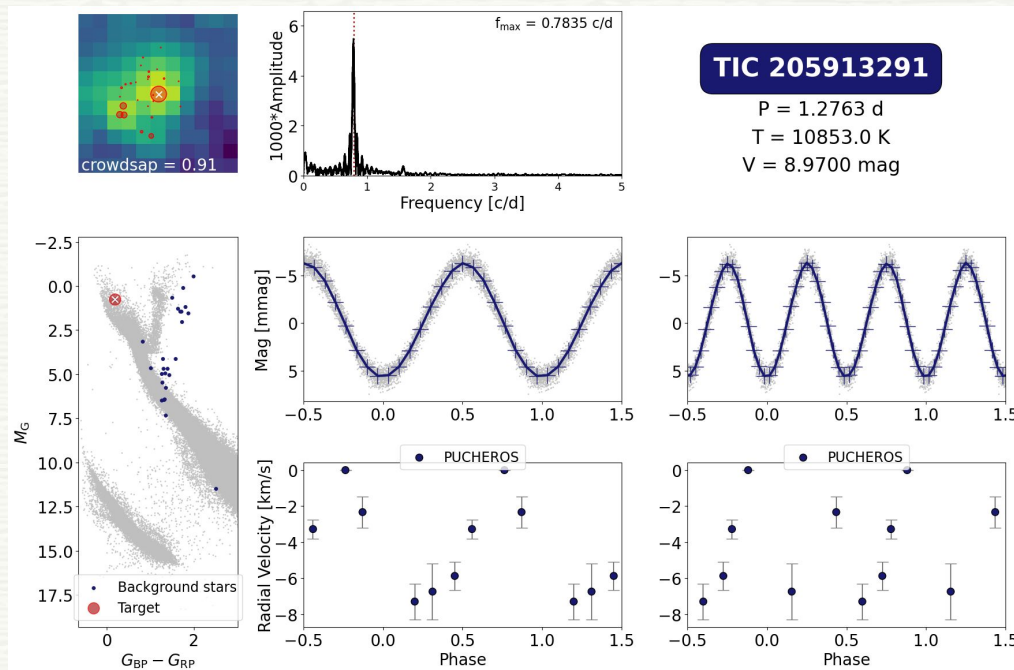
In the fundamental mode, the entire star contracts uniformly, decreasing its radius and increasing its effective temperature.

$$L = 4\pi R^2 \sigma T^4$$

Maximum brightness happens near minimum radius, when the temperature is the highest.

The outer layers momentarily come to rest relative to the observer, resulting in no Doppler shift in spectral lines.

- Binary stars
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Classification

Candidates for spots

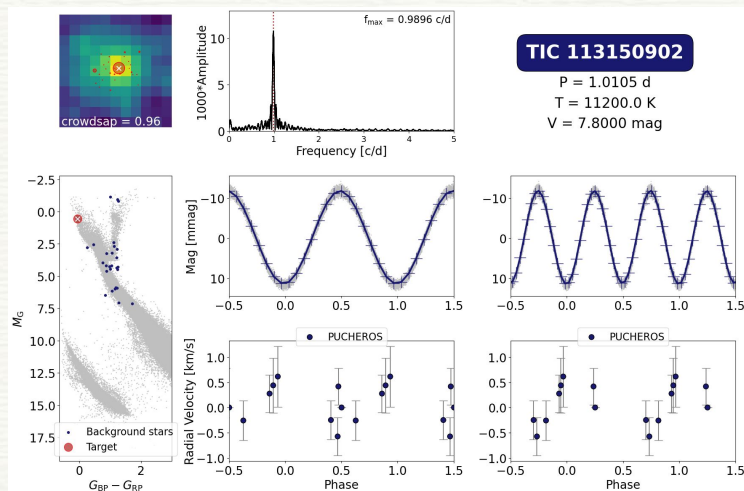
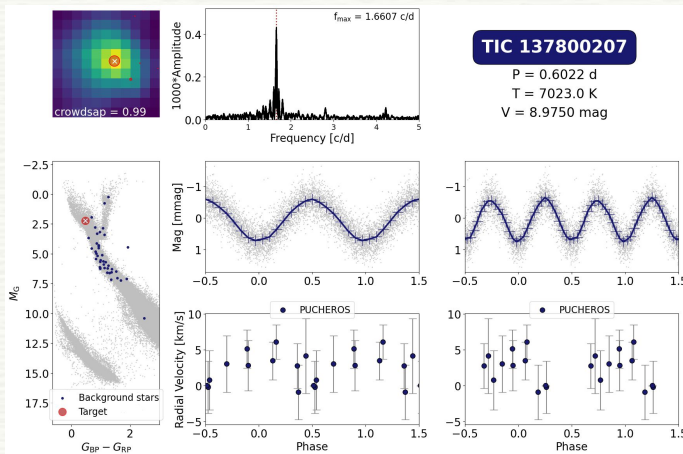
Radial velocity measurements close to zero

- **confined to the rotating atmosphere** -
may produce only minimal radial velocity
variations as they traverse the disk

Spots often radiate differently than the
surrounding photosphere - brightness
variations on the order of **millimagnitudes**

Another way how to produce such
variations: a binary system with low
inclination angles - light curve shows slight
variations, radial velocity close to zero

Distinguishing between the cases: analysis
of chemical abundances, multicolour
photometry - out of scope



- Binary stars
- Pulsating stars
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Classification

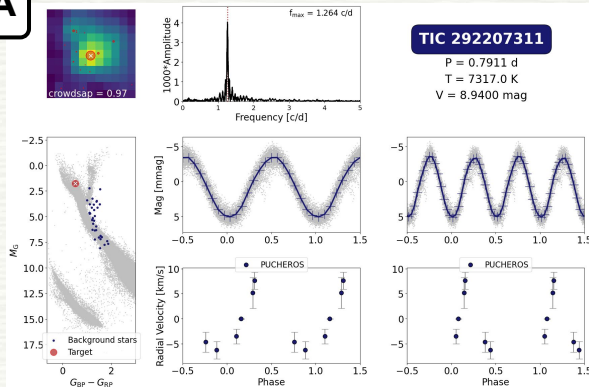
Uncertain objects

Several reasons for “unclear” tag:

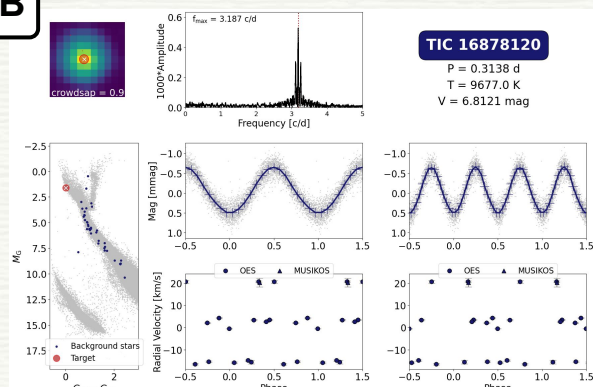
- A. impossible to distinguish variability with P and 2P
- B. no variability in the radial velocity measurements, and the spread of the data was significant and could not be attributed to the noise
- C. not enough spectroscopic measurements
- D. object was a blend

- Binary stars
- Pulsating stars
- Candidates for spots
- Uncertain objects

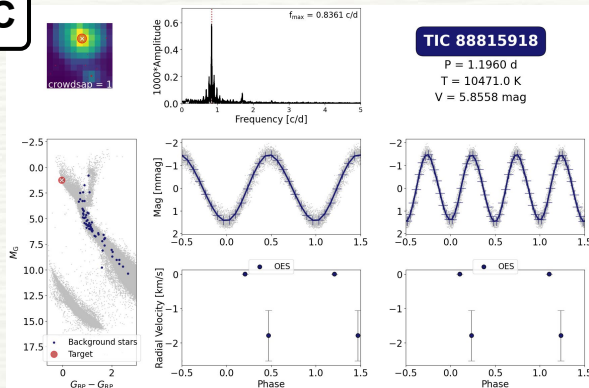
A



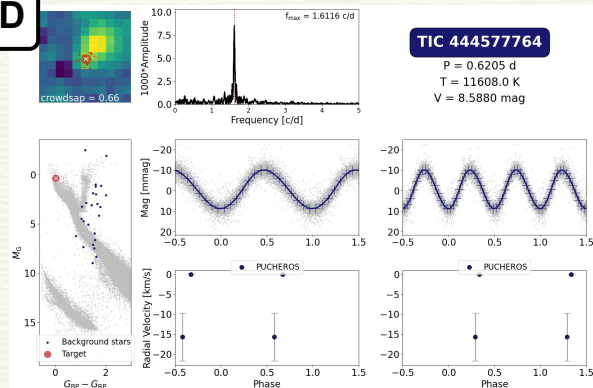
B



C



D



Results

Spectroscopic Follow-up:

- **50%** binary stars (17 objects)
- **26%** candidates for spots (9 objects)
- **21%** unclear classification (7 objects)
- **3%** pulsating stars (1 object)

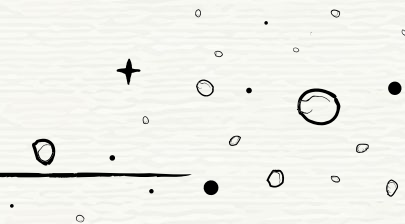
Misclassifications (2 systems):

- **2** binary systems misclassified as pulsators

New Discoveries:

- **7** new spectroscopic binary systems
- **1** new pulsating star
- **1** candidate for multiple star system

Summary



Successfully identified a sample of sinusoidally variable stars using combined **photometric** (TESS) and **spectroscopic** analysis.

Spectroscopic follow-up confirmed the reliability of initial classifications for the majority of targets

Highlighted the complexity of stellar variability and classification challenges.

The Detective's Guide to Stellar Variability:

Thank you for your attention!

When you have eliminated the impossible,
whatever remains, however improbable,
must be the truth

- Arthur Conan Doyle

