Disentangling the stellar activity of Barnard's Star

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Instituto de Astrofísica de Canarias

OUTLINE

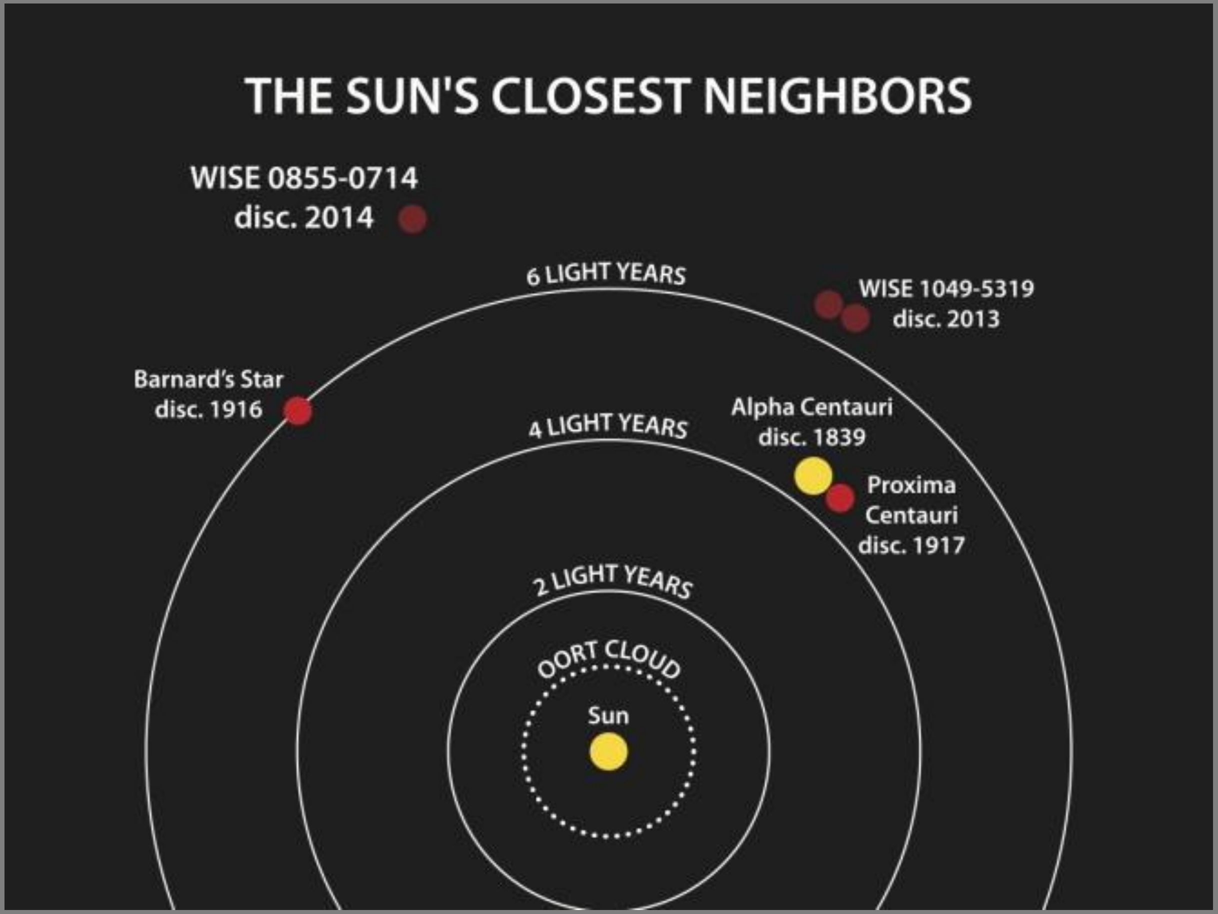
- Introduction
- Analysis
- Results
- Conclusions

INTRODUCTION

Star

Data

- **Barnard’s Star (GJ 699):**
  - Closest single star system to the Sun



Star

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- **Barnard's Star (GJ 699):**
  - Closest single star system to the Sun
  - Highest proper motion known to date

Parameter	GJ 699	Ref.
RA (J2000)	17:57:48.50	[1]
DEC (J2000)	+04:41:36.11	[1]
$\mu_\alpha \cos\delta$ (mas yr^{-1})	-802.8 ± 0.6	[1]
μ_δ (mas yr^{-1})	+10362.5 ± 0.4	[1]
Distance [pc]	1.8266 ± 0.0001	[1]
$m_{\rm B}$	11.24	[2]
$m_{\rm V}$	9.51	[2]
Spectral type	M3.5V	[3]
$T_{\rm eff}$ [K]	3278 ± 51	[4]
[Fe/H] (dex)	-0.12 ± 0.16	[4]
$M_\star$ [$M_\odot$]	0.163 ± 0.022	[5]
$R_\star$ [$R_\odot$]	0.178 ± 0.011	[5]
$L_\star$ [$L_\odot$]	0.00329 ± 0.00019	[5]
log g (cgs)	5.10 ± 0.07	[4]
log ($L_X/L_{\rm bol}$)	-5.4	[6]
$v \sin i$ [km s^{-1}]	<3	[4]

Ribas+2018

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  - Age of 7-10 Gyr (Sun: 4.6 Gyr)

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  - Closest single star system to the Sun
  - Highest proper motion known to date
  - Age of 7-10 Gyr (Sun: 4.6 Gyr)
  - Quiet star:
    1. Very low X-ray emission
    2. Lack of Halpha emission
    3. Low variability
  - Benchmark for intermediate M-dwarfs

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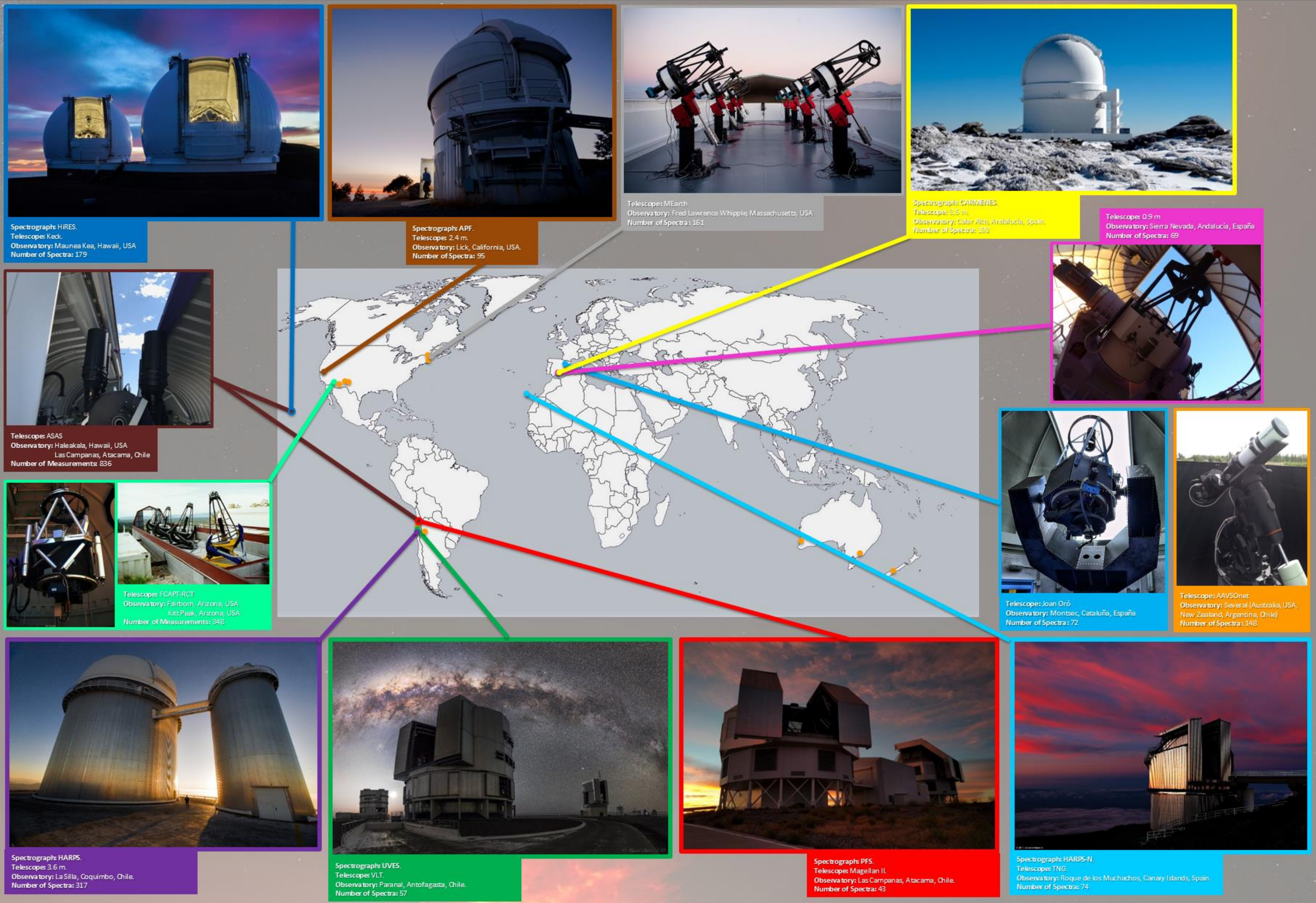
Spectrograph: HiRES.
Telescope: Keck.
Observatory: Maunea Kea, Hawaii, USA
Number of Spectra: 179
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Observatory: Haleakala, Hawaii, USA
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Telescope: FCAPT-RCT
Observatory: Fairborn, Arizona, USA
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Number of Measurements: 348
Telescope: Joan Oró
Observatory: Montsec, Cataluña, España
Number of Spectra: 72
Telescope: AAVSOnet
Observatory: Several (Australia, USA, New Zealand, Argentina, Chile)
Number of Spectra: 148
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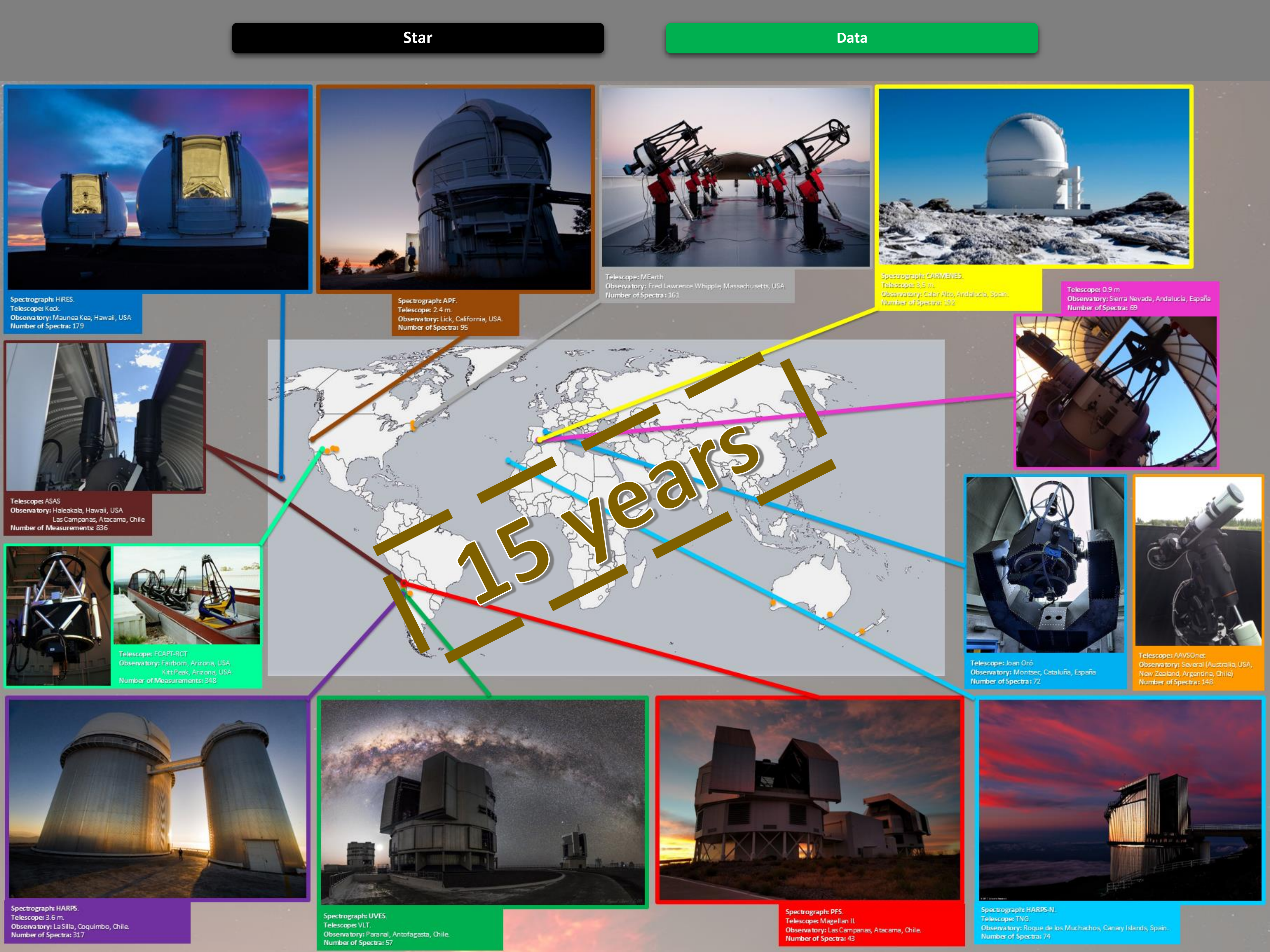
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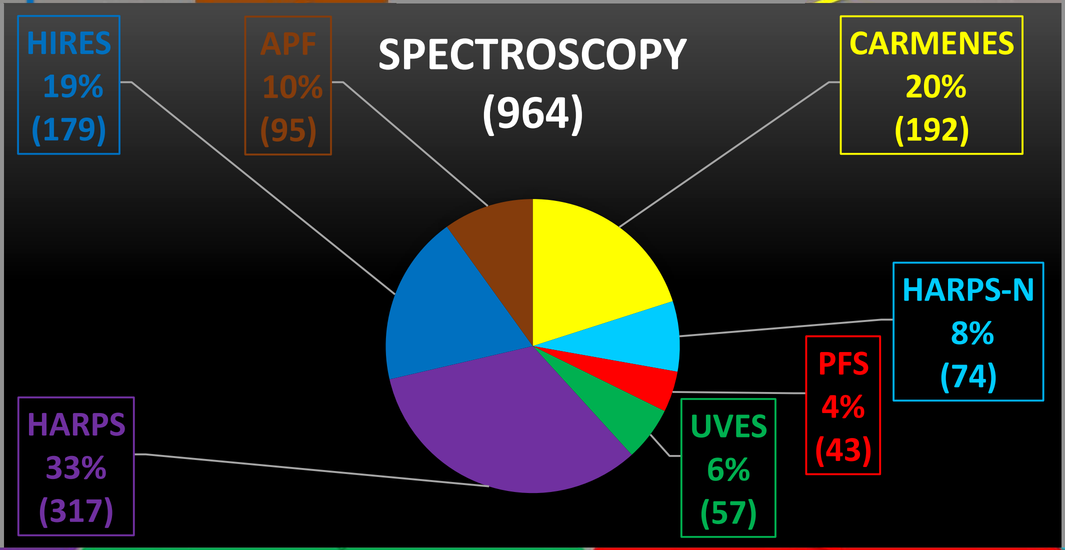

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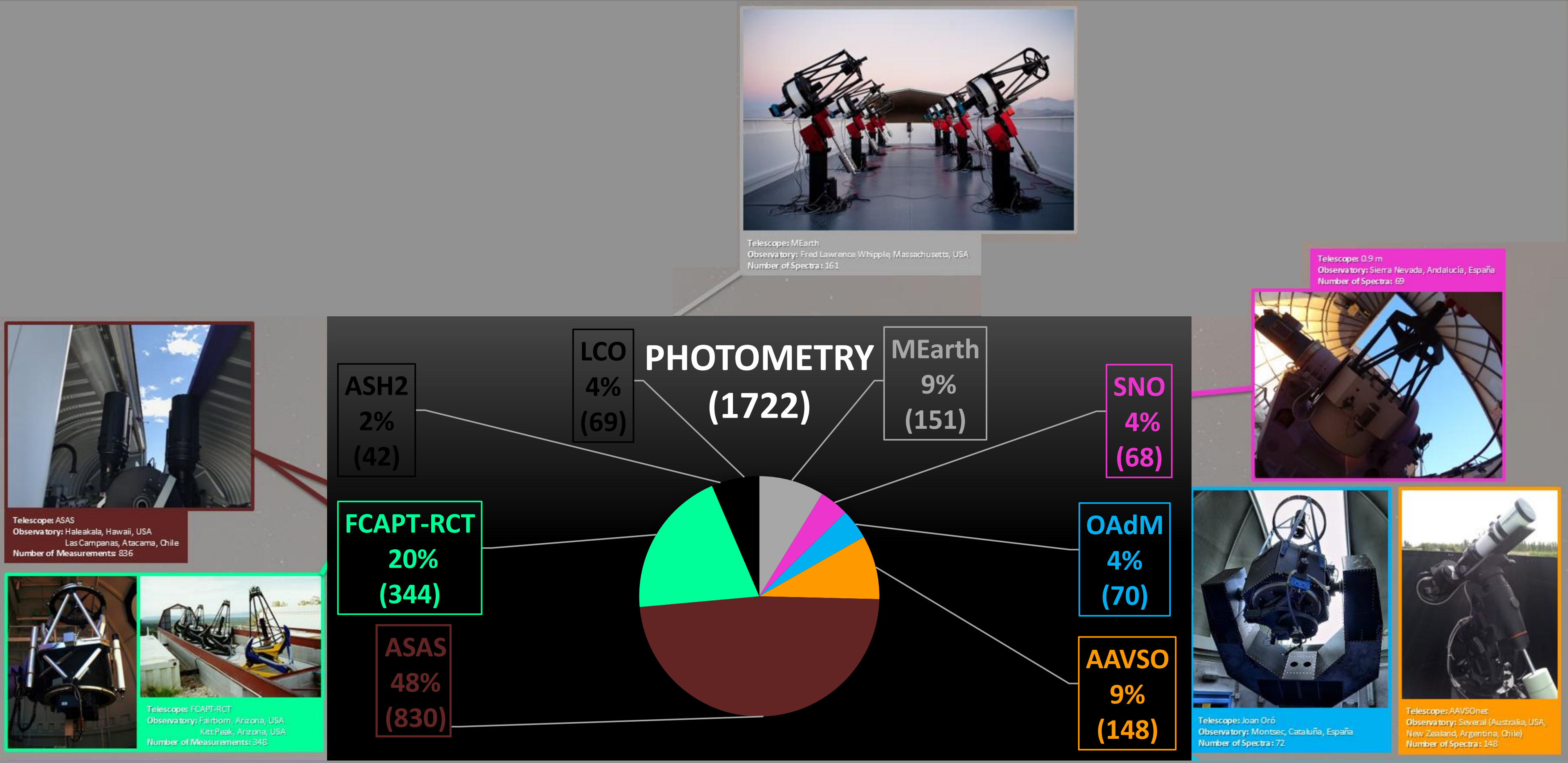
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4%
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ASH2
2%
(42)
MEarth
9%
(151)
SNO
4%
(68)
FCAPT-RCT
20%
(344)
OAdM
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(70)
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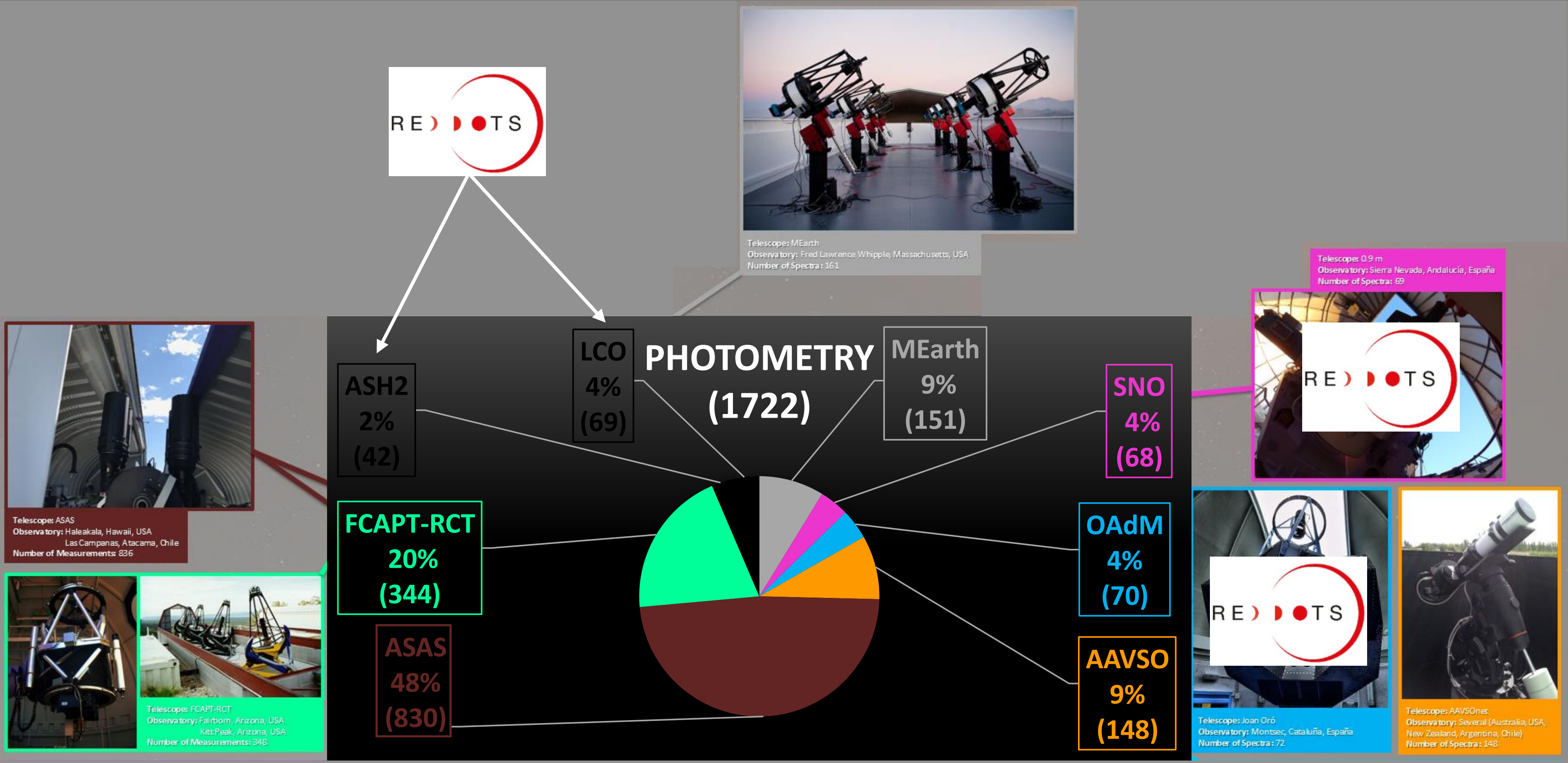
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ANALYSIS

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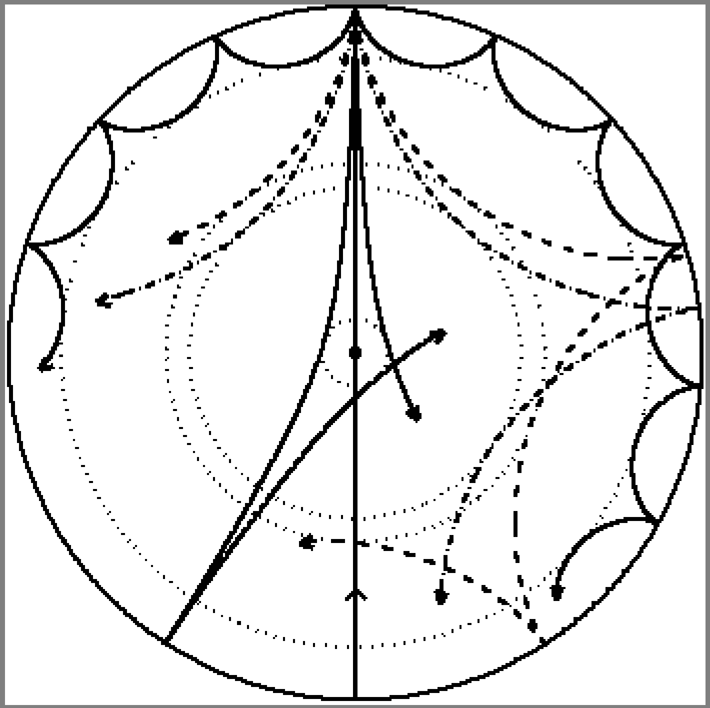
    1. Oscillations: Minutes



- **Stellar Activity:**

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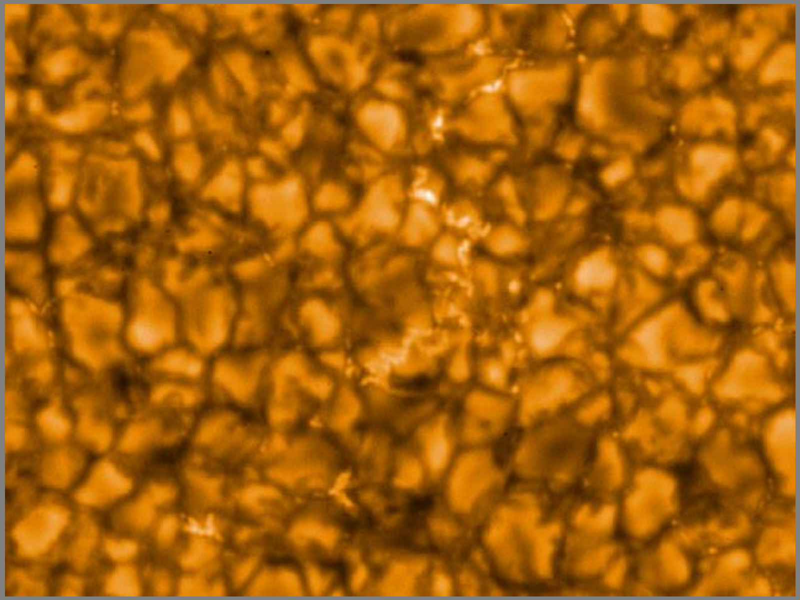

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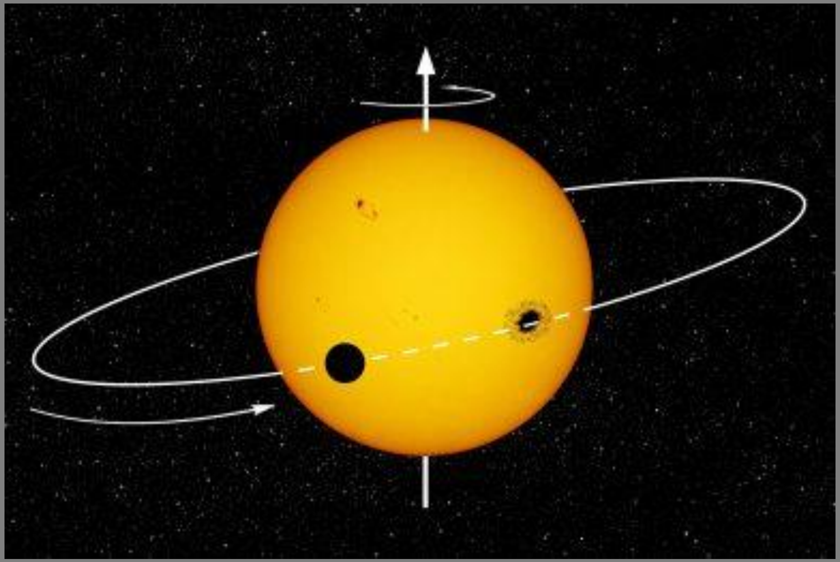
       - Especially important in M-dwarfs



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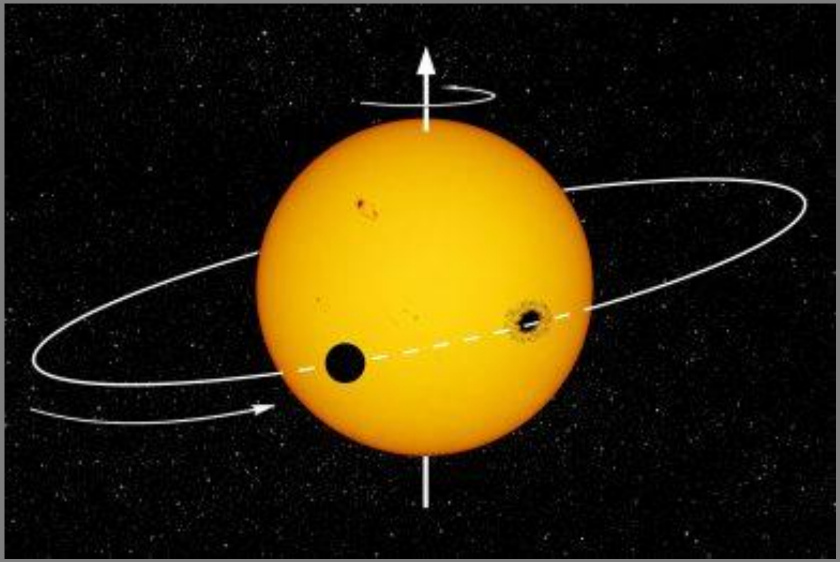

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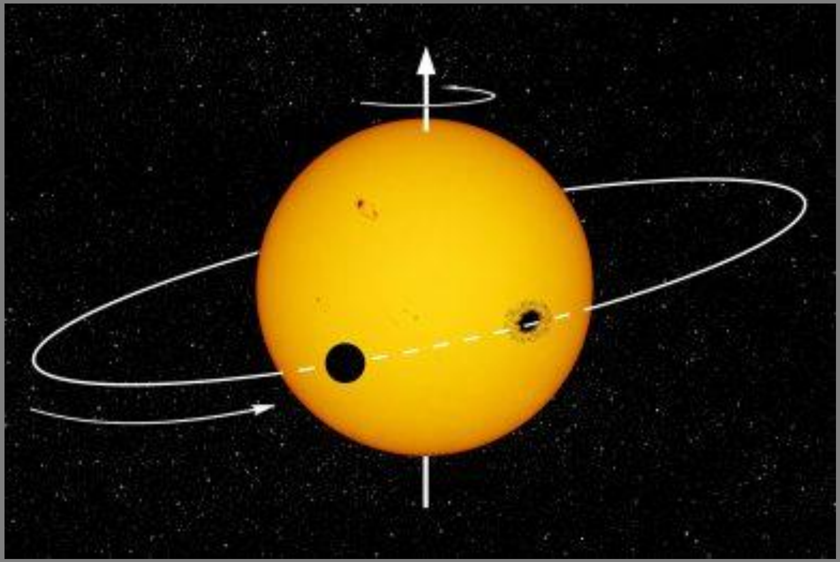

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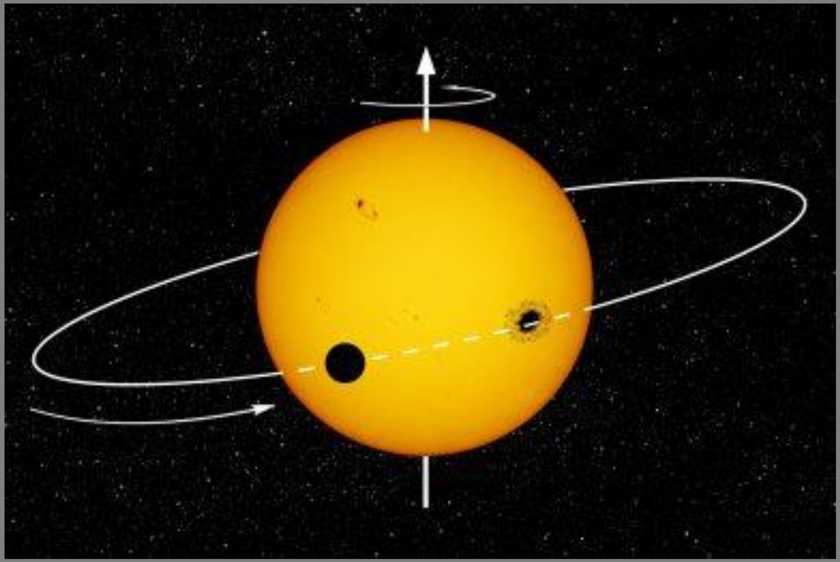

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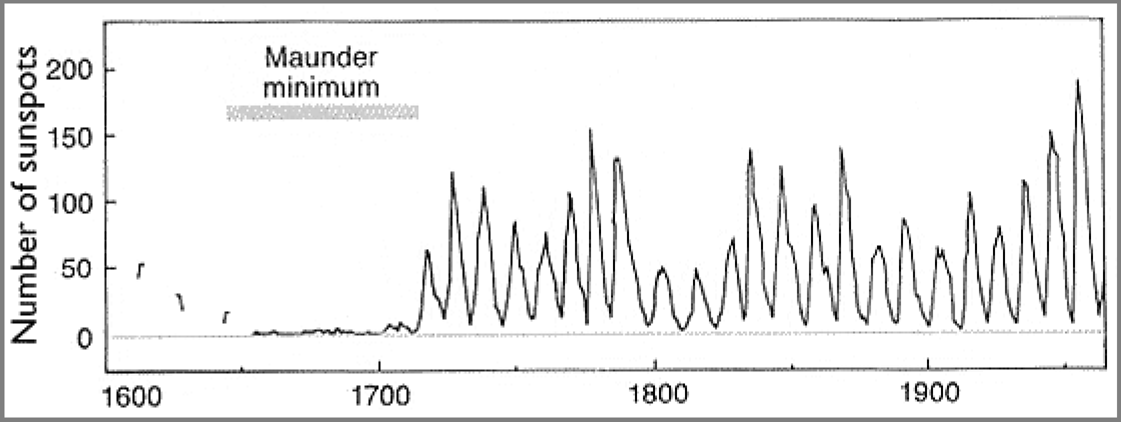

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1. Blaze correction

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   b) Other spectrographs: Second order polynomial

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4. Weights per echelle order

- **Indices:**

  1. Hα

$$H = \frac{A}{L + R}$$

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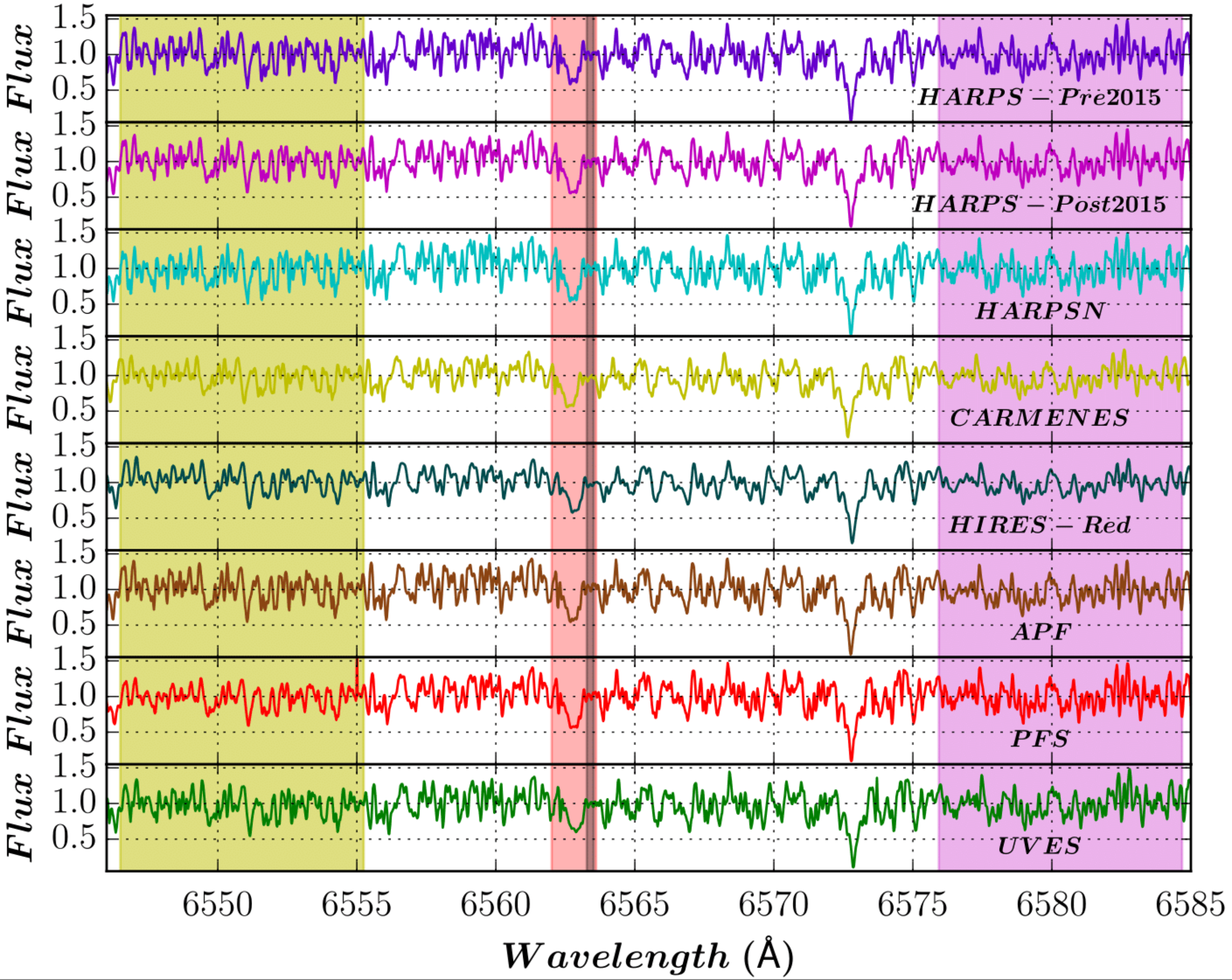

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$$S = \frac{H + K}{R + V}$$

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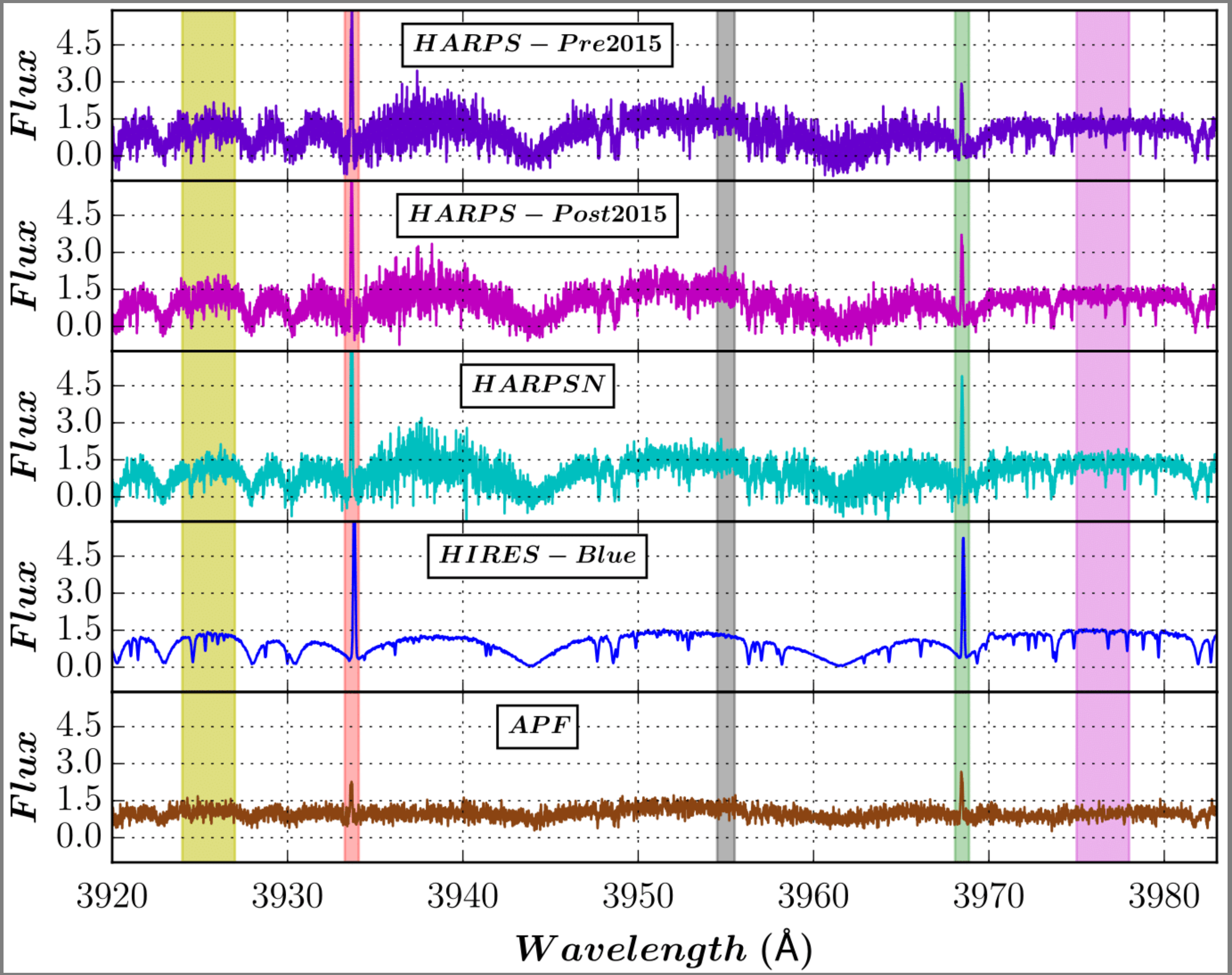

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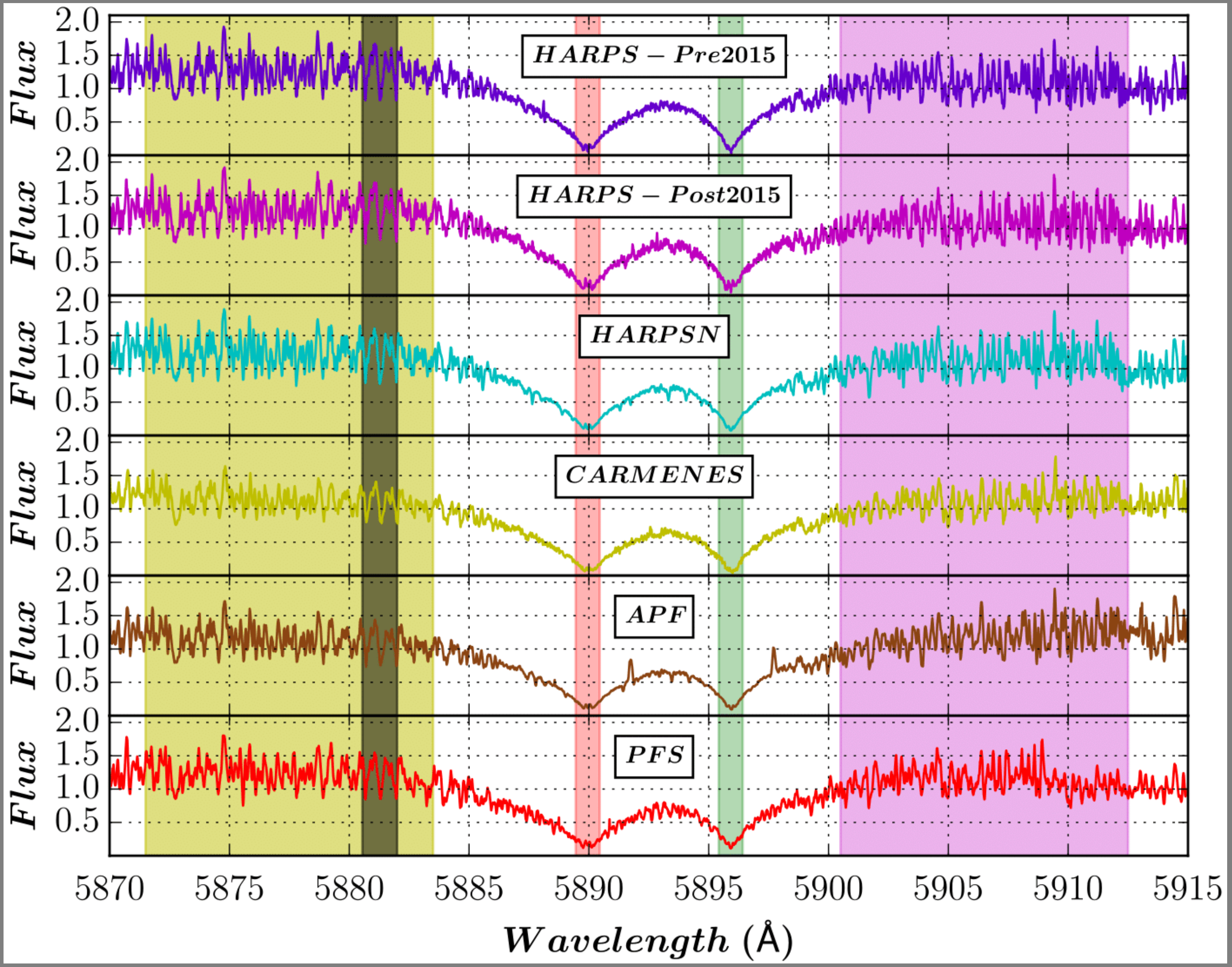

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4. FWHM

$$FWHM = 2\sqrt{2\ln(2)}\,\sigma$$

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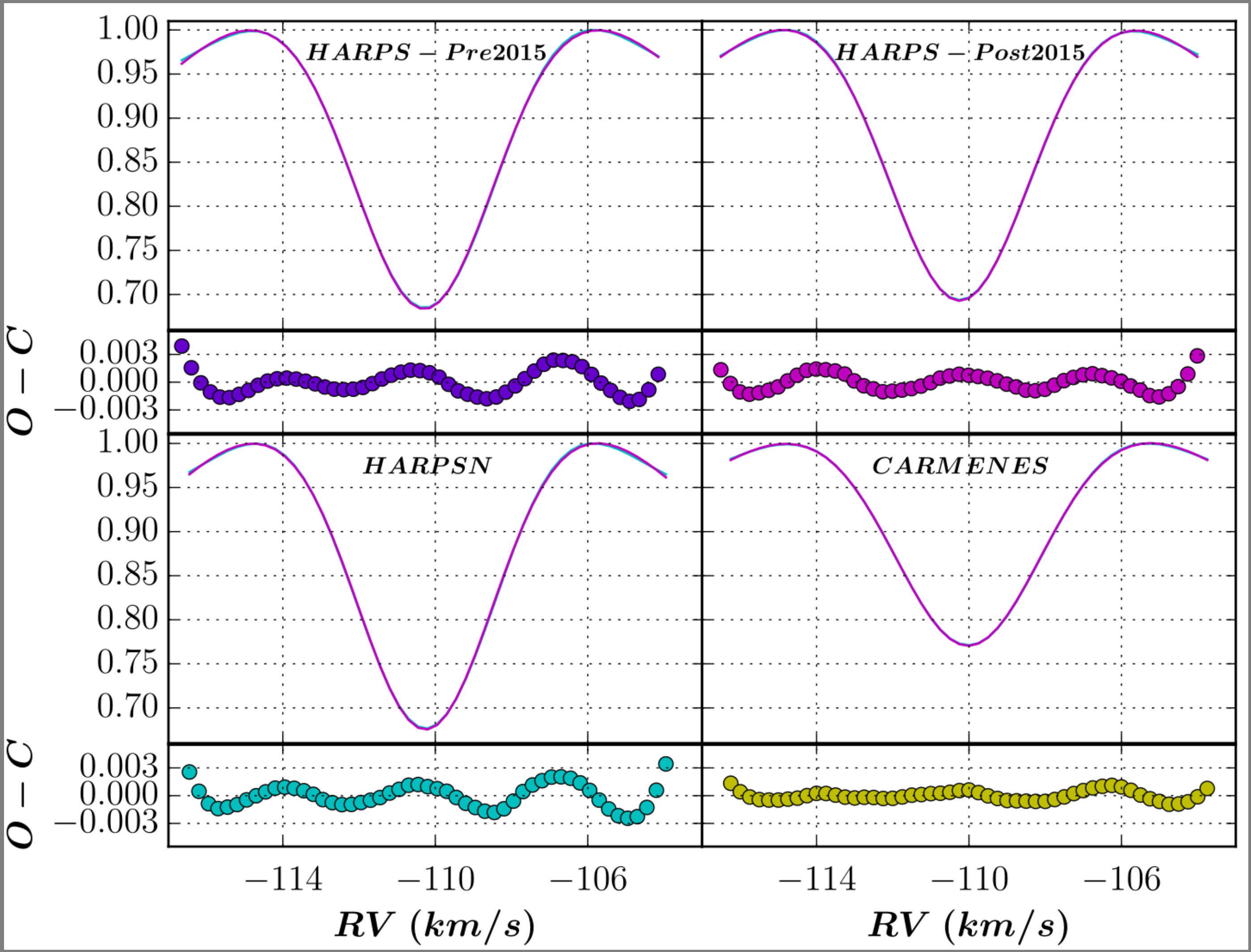

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5. Photometric Magnitudes

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Observatory/ Survey/ Telescope	Aperture [m]	Filter	Error [mmag]	RMS [mmag]
ASAS-3	0.07	*V*	10.3	17.0
ASAS-3N	0.10	*V*	13.0	16.1
ASAS-SN	0.14	*V*	5.2	8.3
Combined ASAS	0.07, 0.10, 0.14	*V*	10.4	16.8
FCAPT & RCT	0.80, 1.30	*V*	4.9	11.2
MEarth	0.40	*RG715*	16.5	6.5
SNO	0.90	*B*	4.5	5.4
		V	4.4	6.4
		R	5.8	5.3
OAdM	0.80	*R*	7.2	9.6
		I	8.4	8.8
AAVSO	Range	*V*, *BRIHα*	15.1	8.9
LCO	0.40	*V*	16.0	30.5
		r'	31.1	45.2
		i'	91.4	75.6
ASH2	0.40	[OIII]	14.1	7.1
		Hα	23.9	12.5
		[SII]	16.8	9.5

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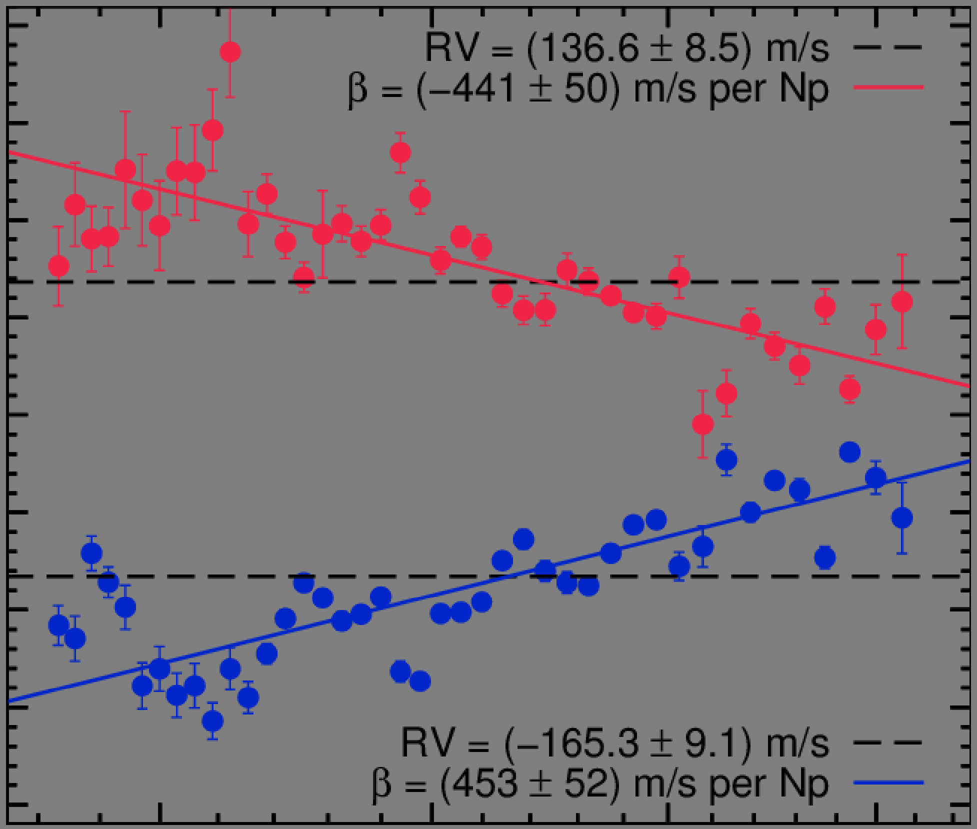
6. Chromatic Index



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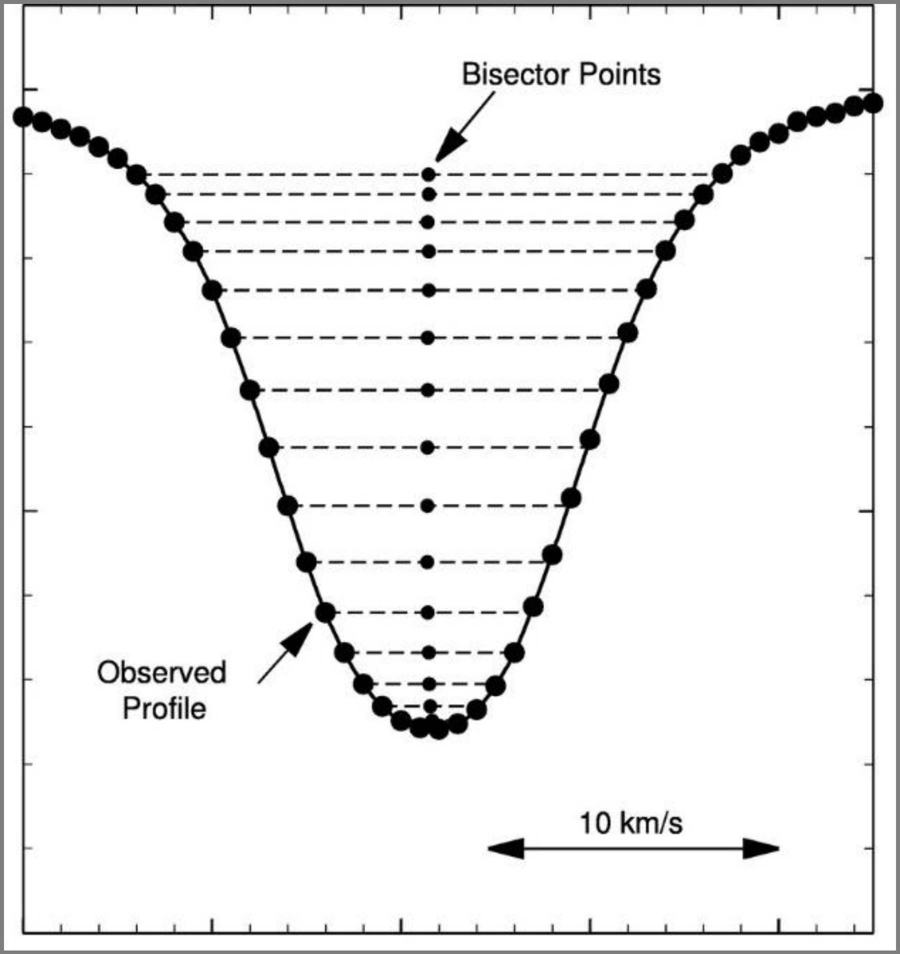
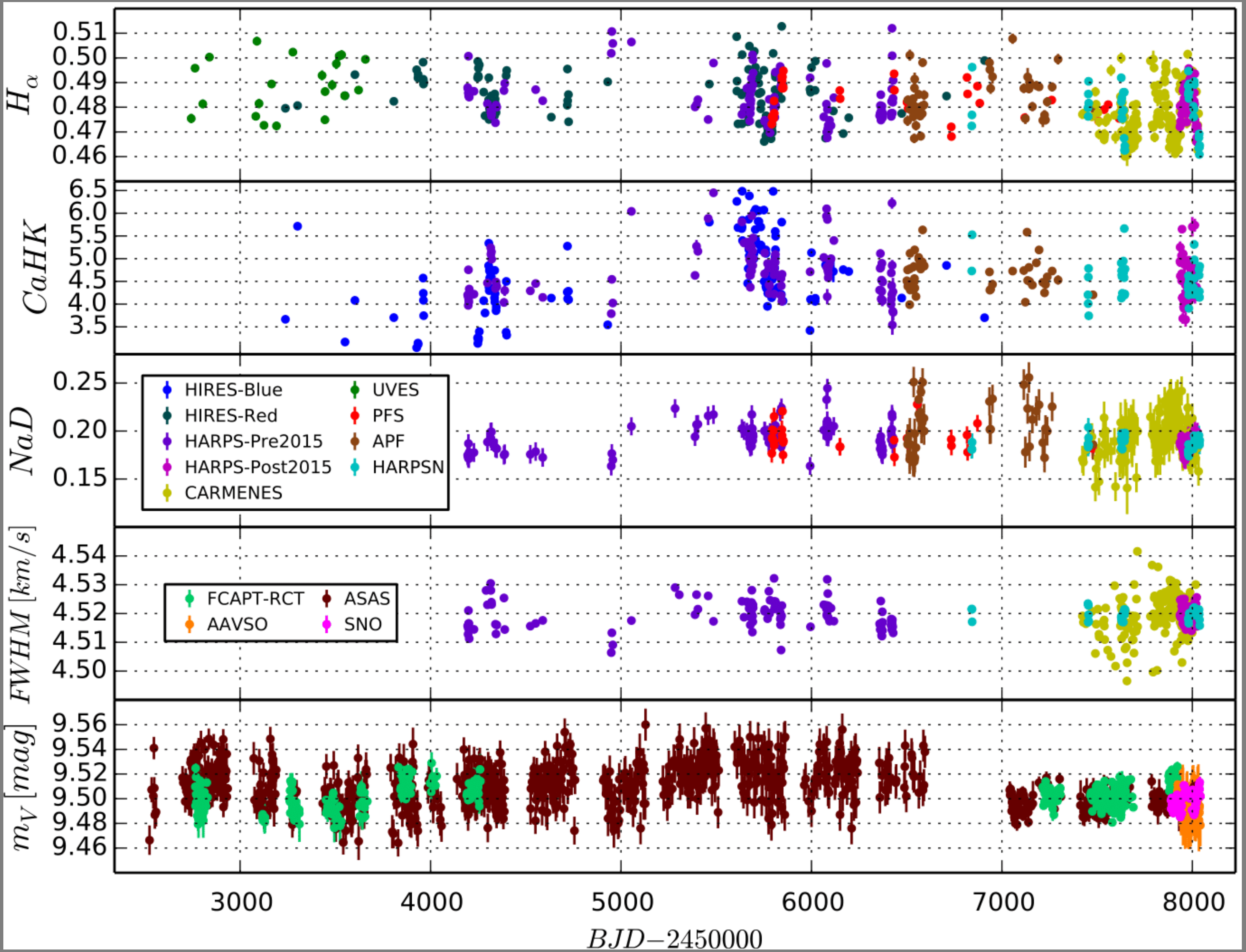
7. Bisector Span



Stellar Activity Sources | **Stellar Activity Indicators** | Time-Series Analysis

- **Subsequent Process:**
  1. Average per night
     a) 2σ in values
     b) 3σ in errors



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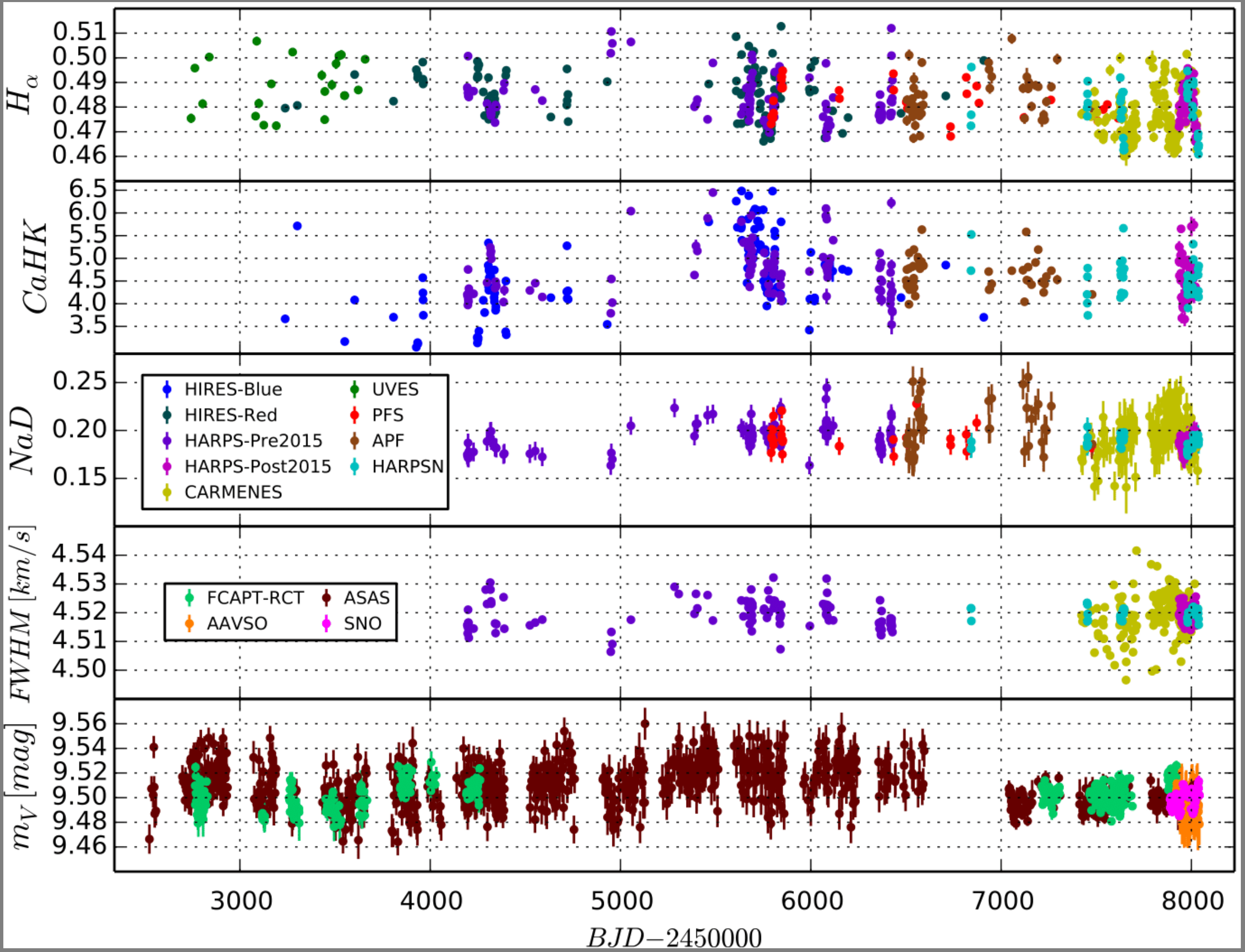
- **Subsequent Process:**
  1. Average per night
     a) 2σ in values
     b) 3σ in errors
  2. Remove outliers
     - Flares



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- **Subsequent Process:**
  1. Average per night
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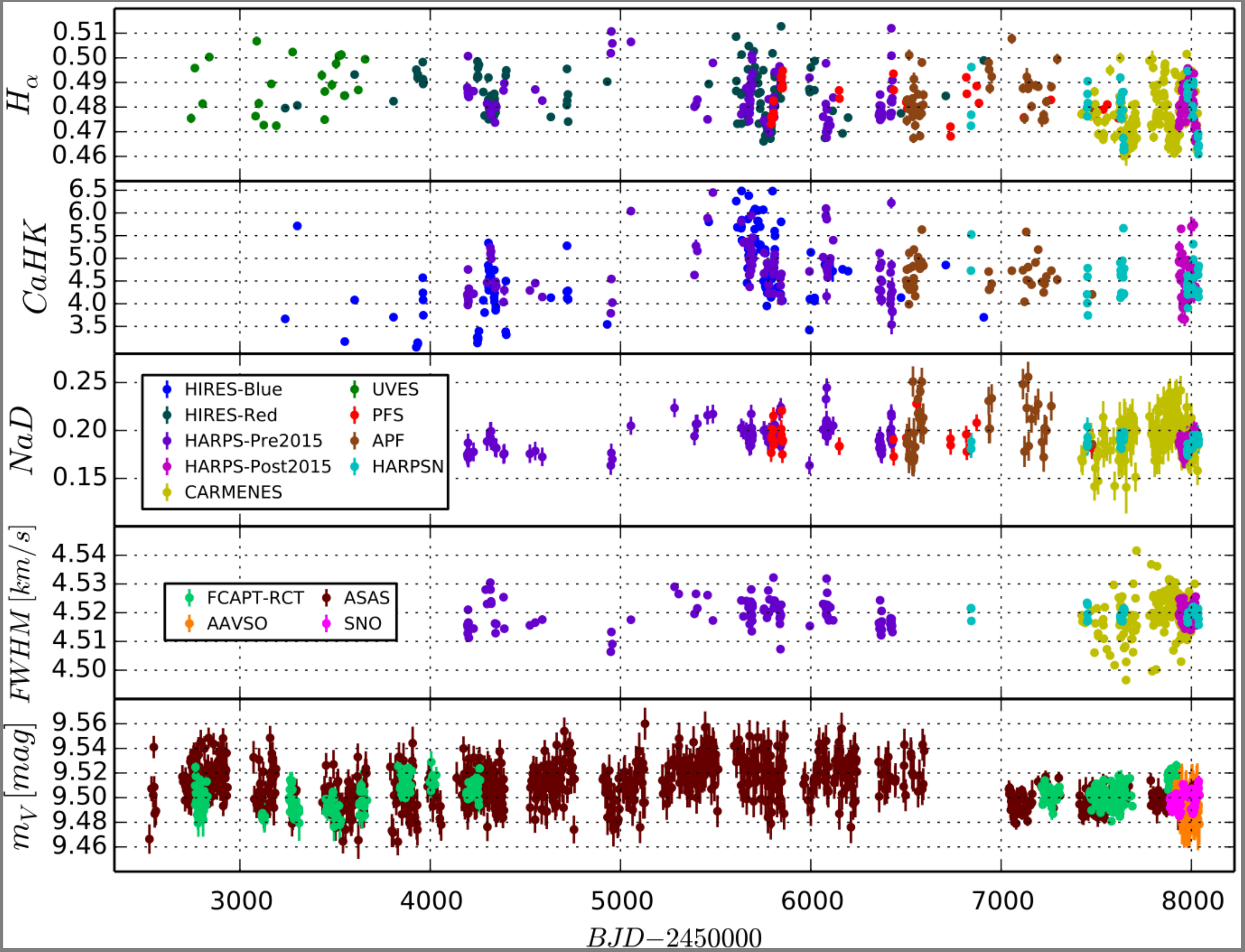
     b) 3σ in errors
  2. Remove outliers
     - Flares
  3. Offsets
     - Time Windows



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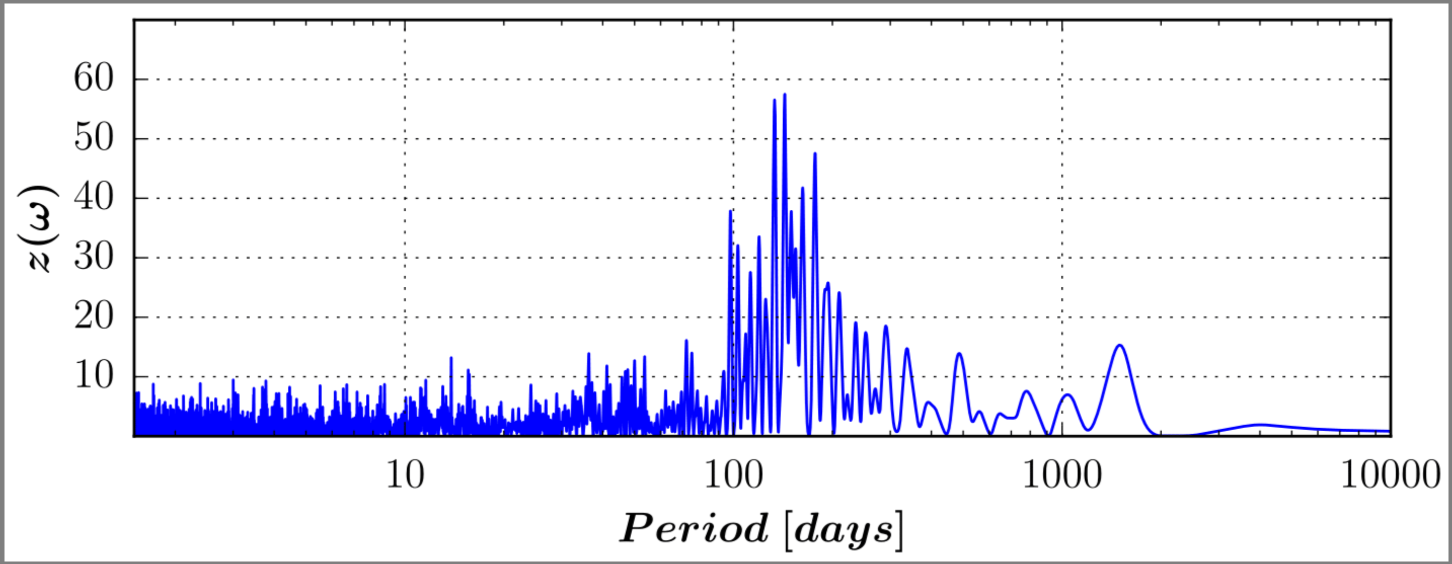
- **Structure:**

1. Generalized Lomb-Scargle periodogram (GLS)

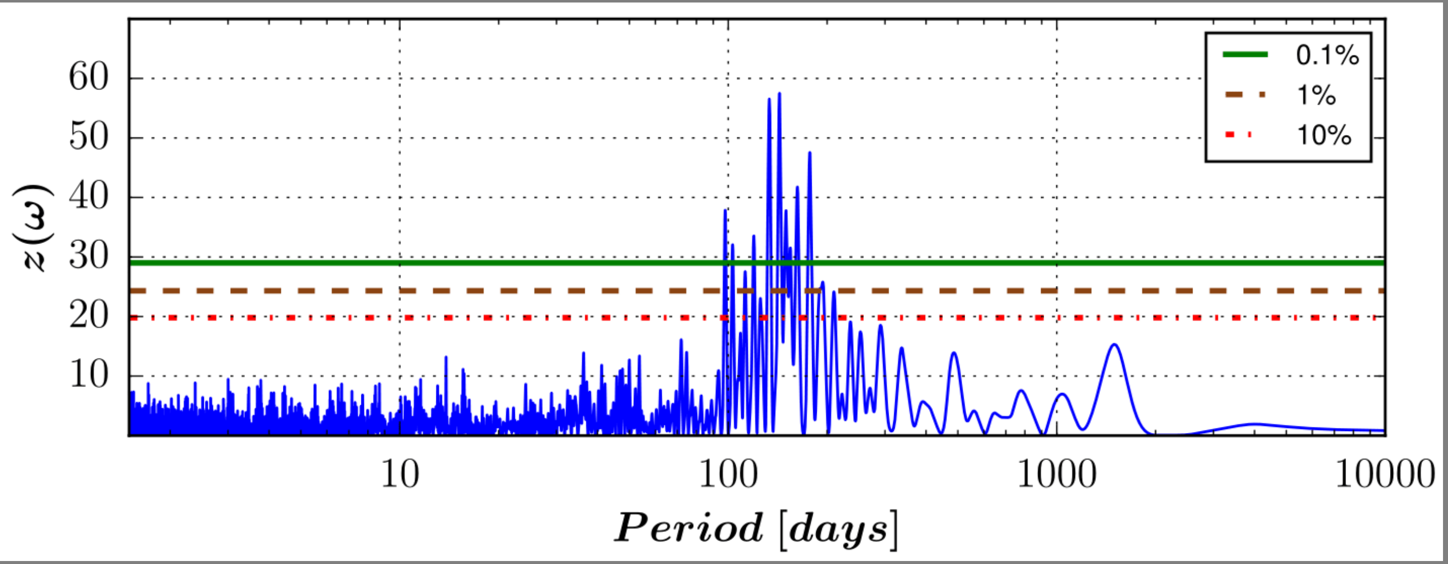


- **Structure:**

  1. Generalized Lomb-Scargle periodogram (GLS)

  2. False Alarm Probability (FAP) levels from Bootstrapping

     - 10000 iterations



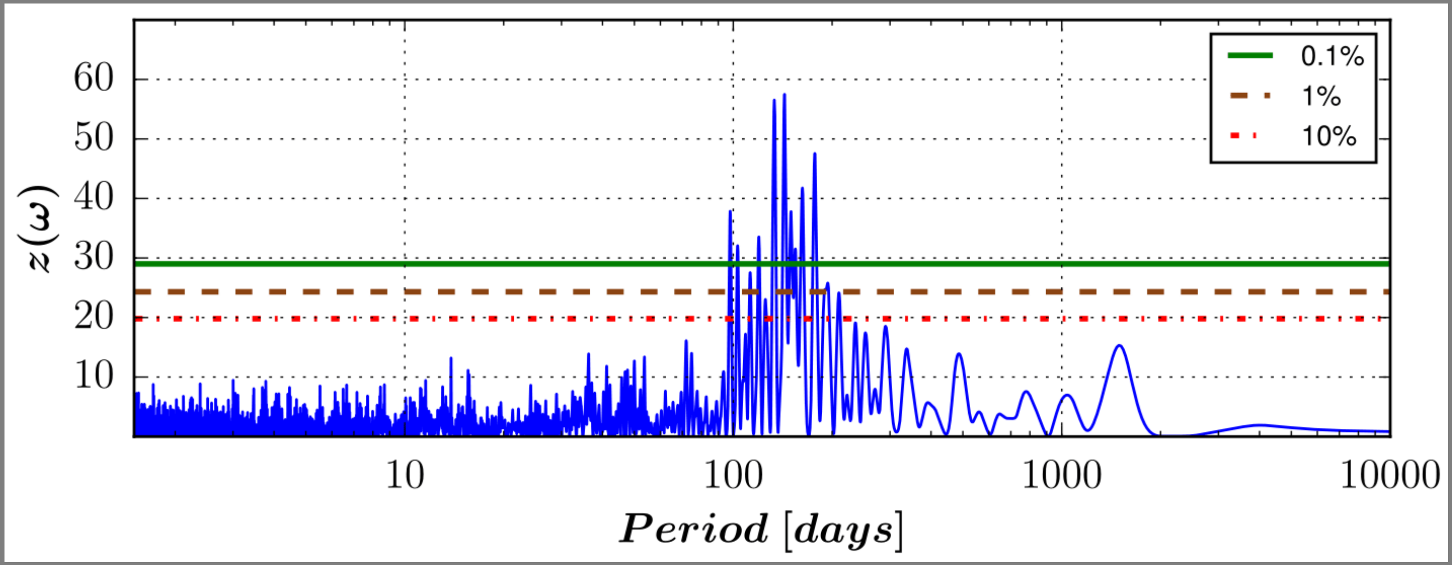
- **Structure:**

1. Generalized Lomb-Scargle periodogram (GLS)

2. False Alarm Probability (FAP) levels from Bootstrapping

    - 10000 iterations

3. Pre-whitening for a single instrument



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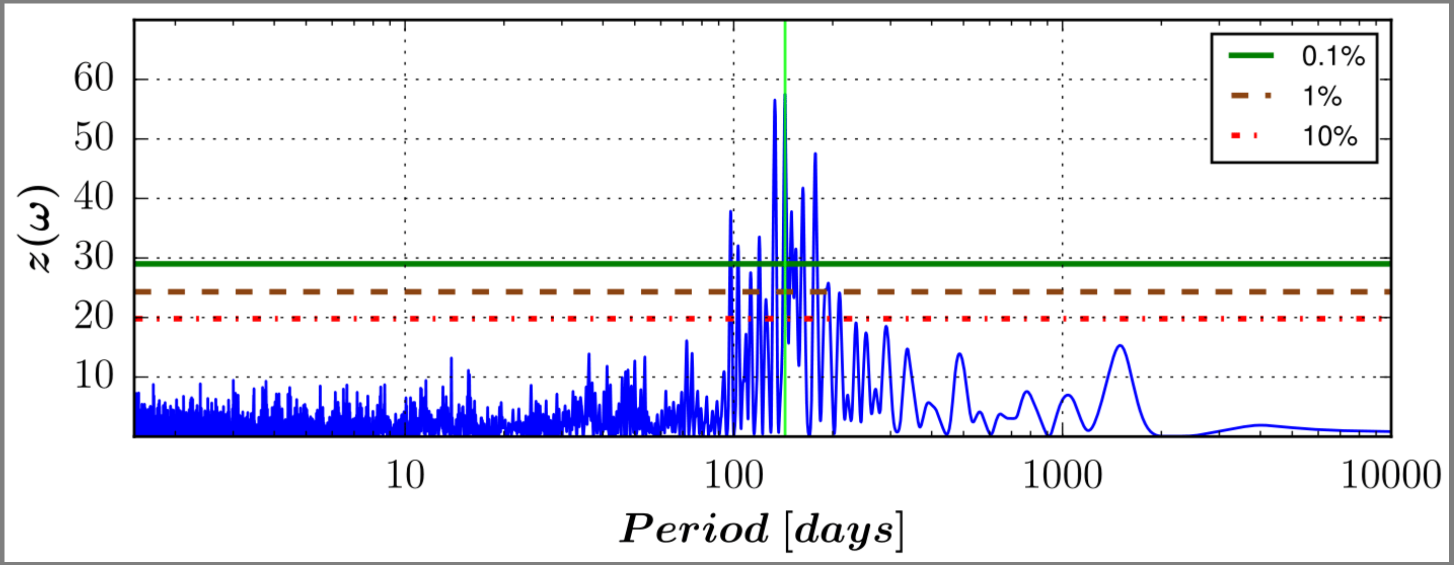

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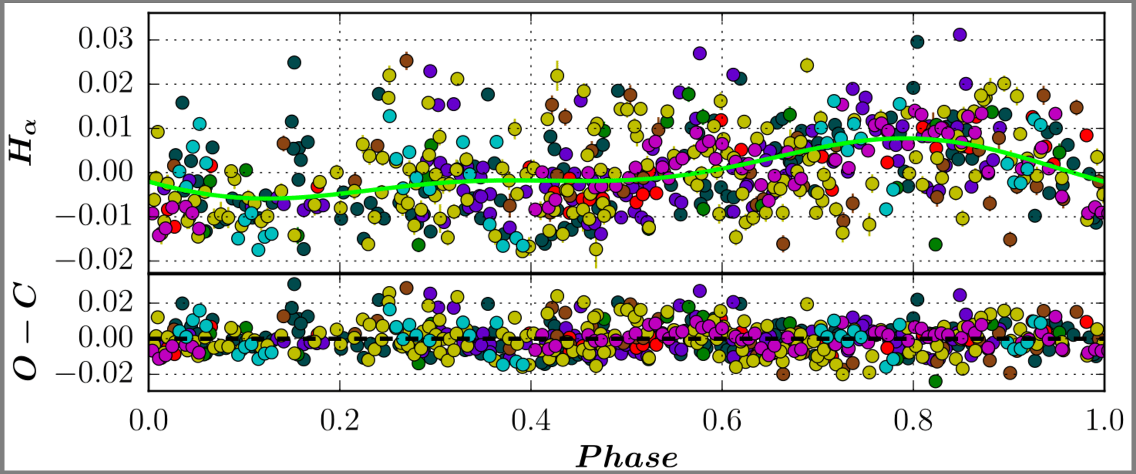

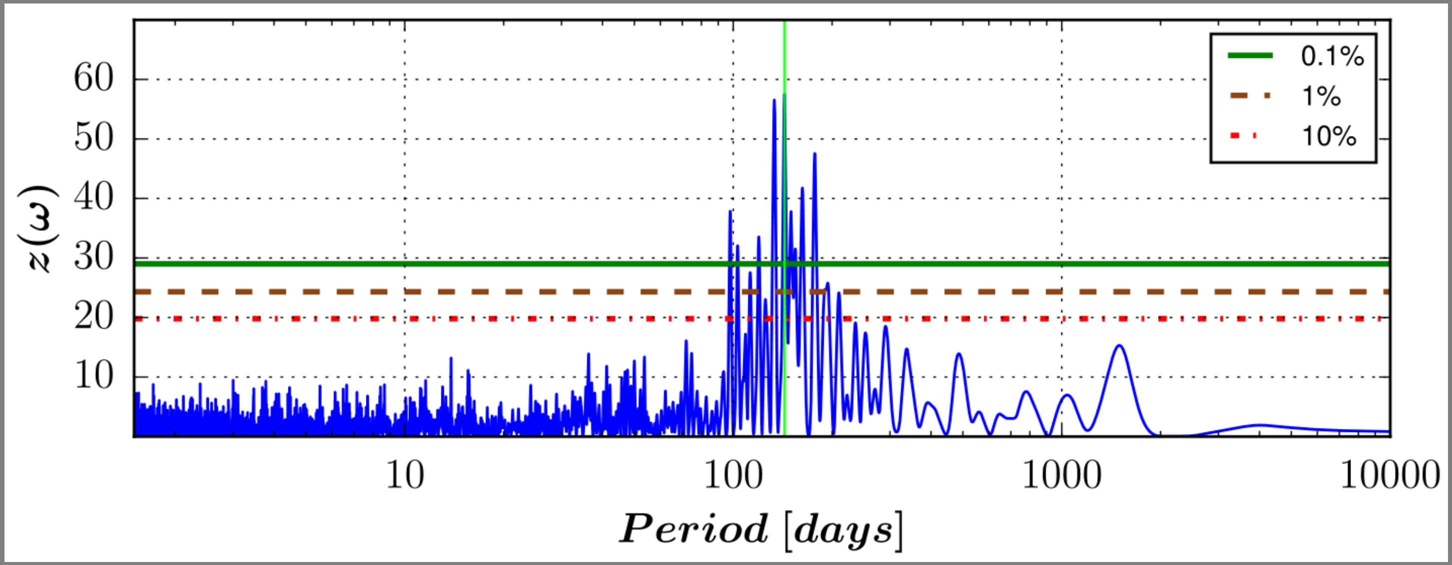

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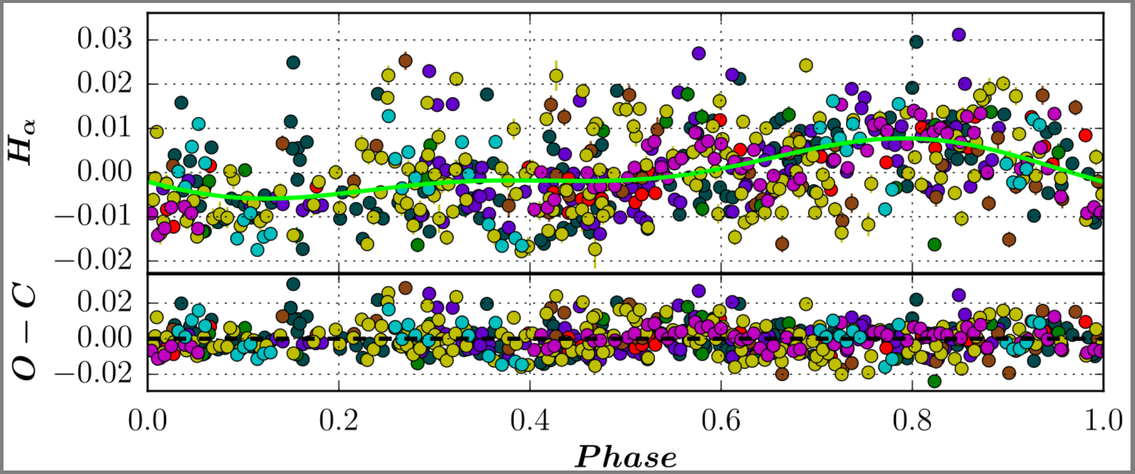

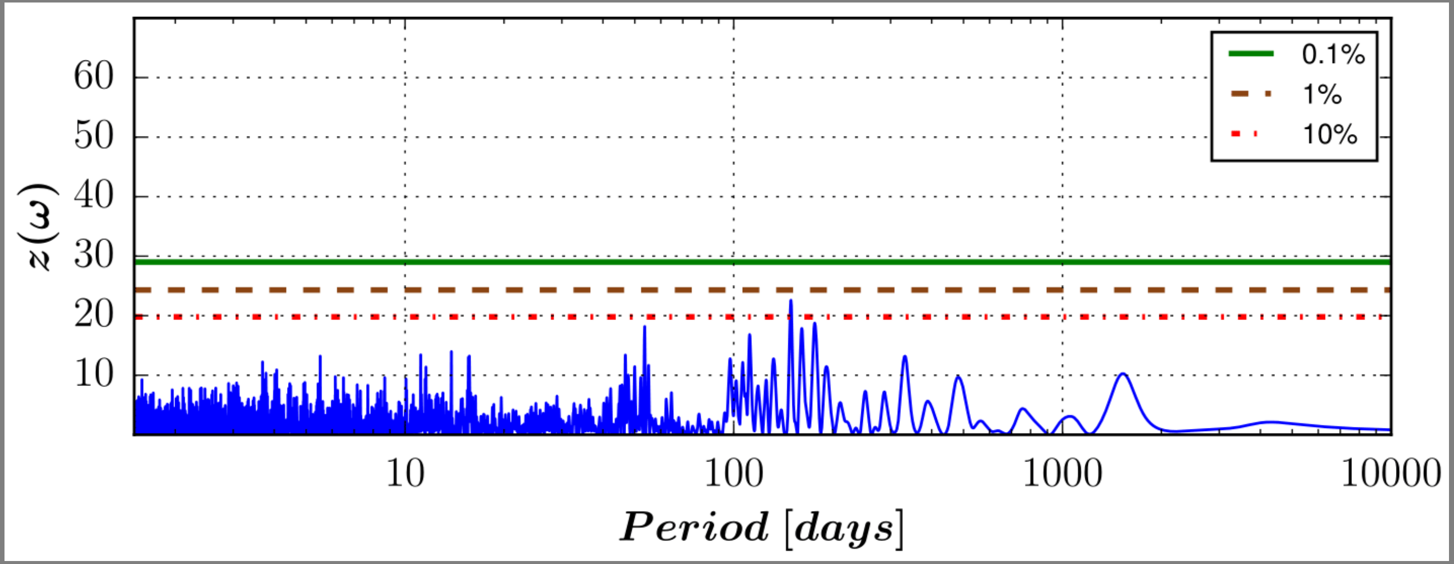

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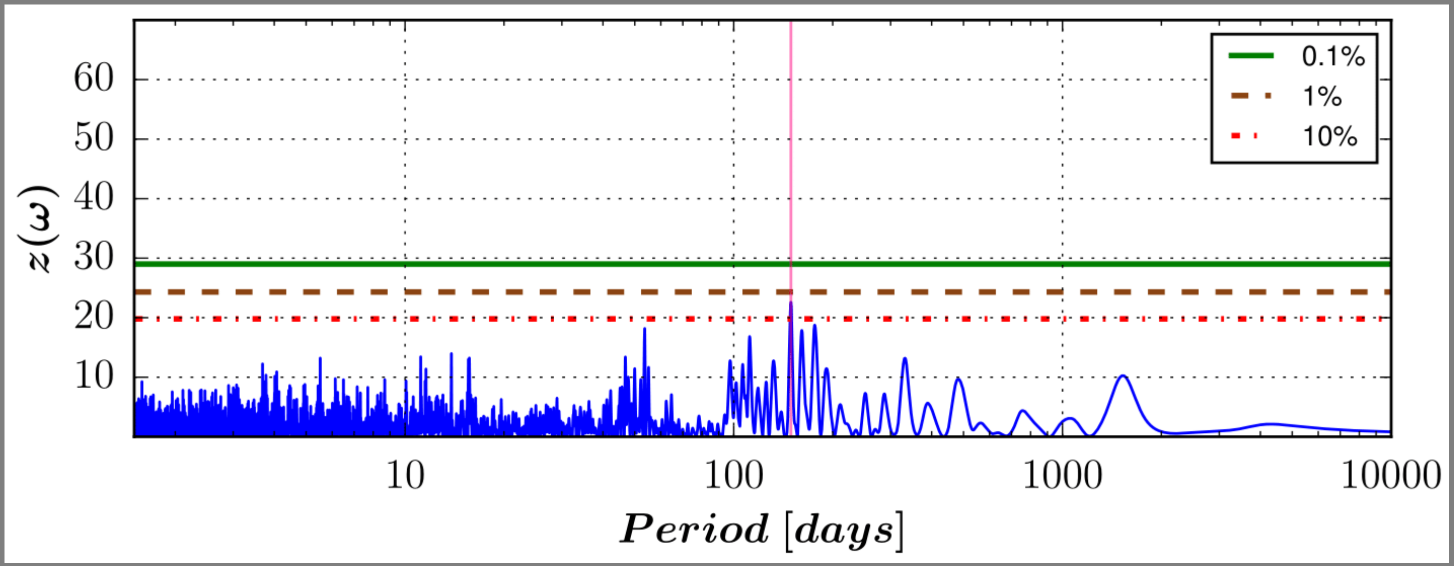

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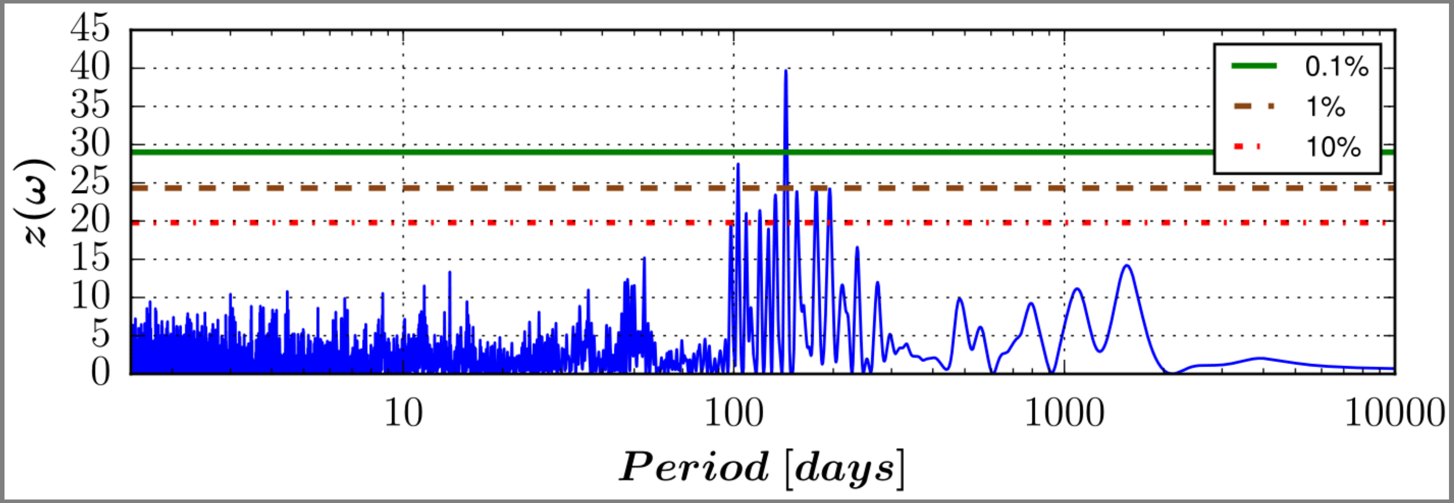
4. Isolate each individual signal



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Signal to be isolated

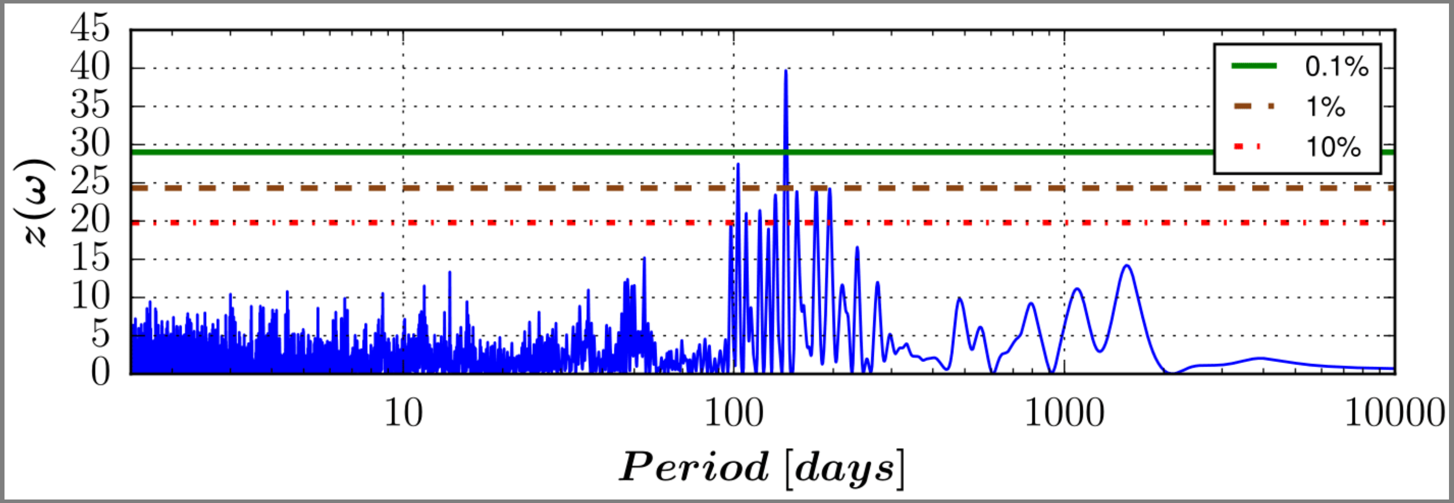
Model to be subtracted

P_1

P_2

P_3

P_4



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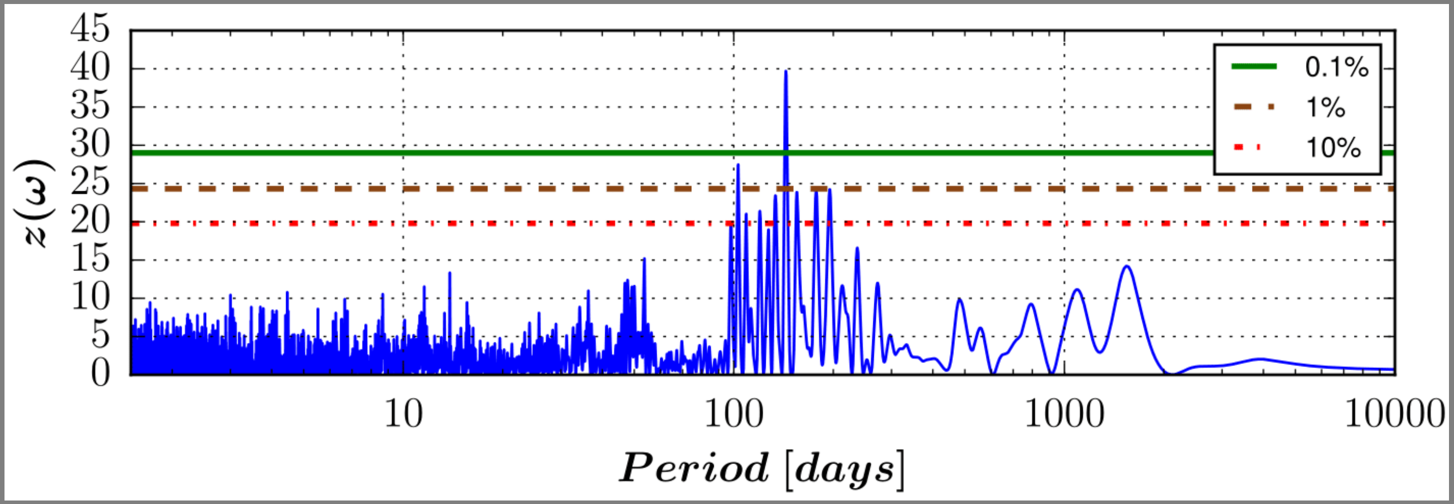

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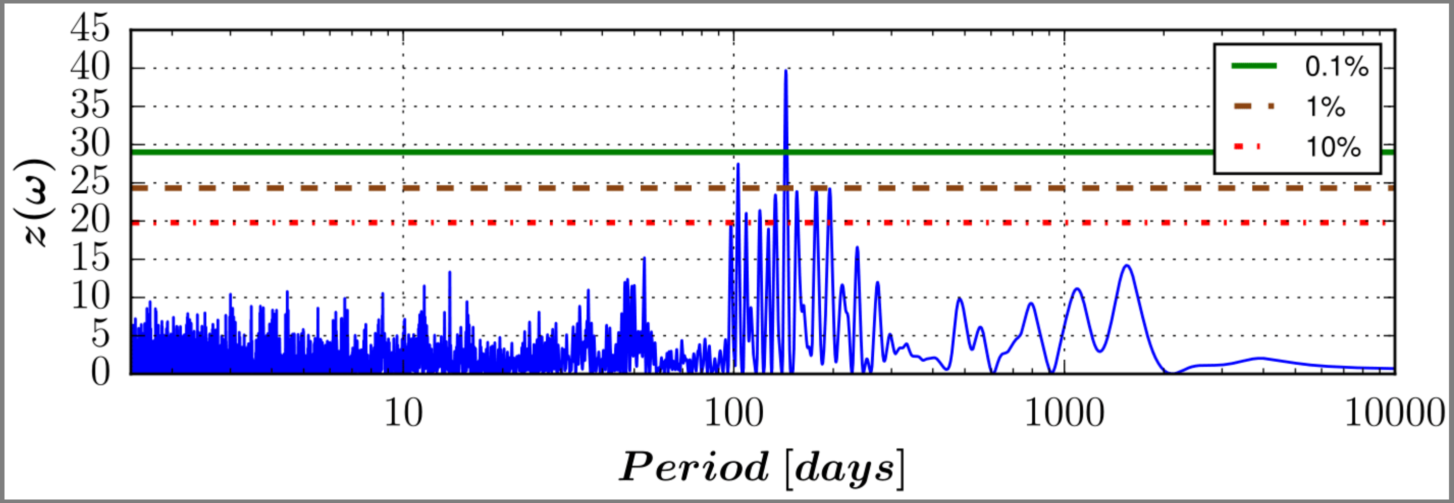

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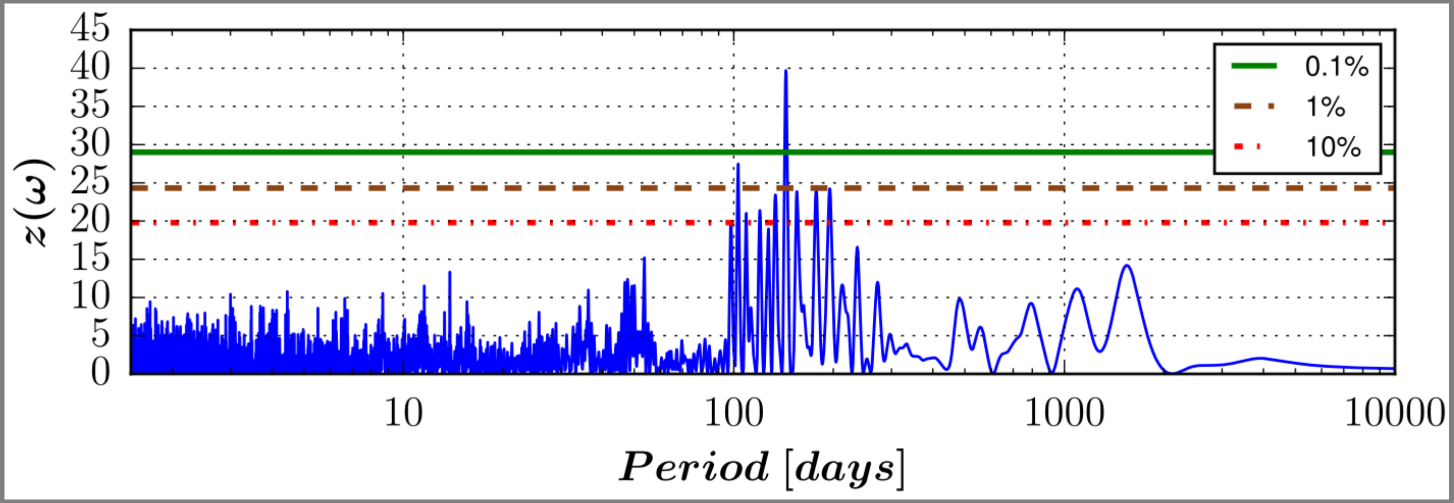

RESULTS

- **Results:**
  - 618 measurements
    - <H>=0.48
    - Mean Error=0.001
    - RMS=0.01

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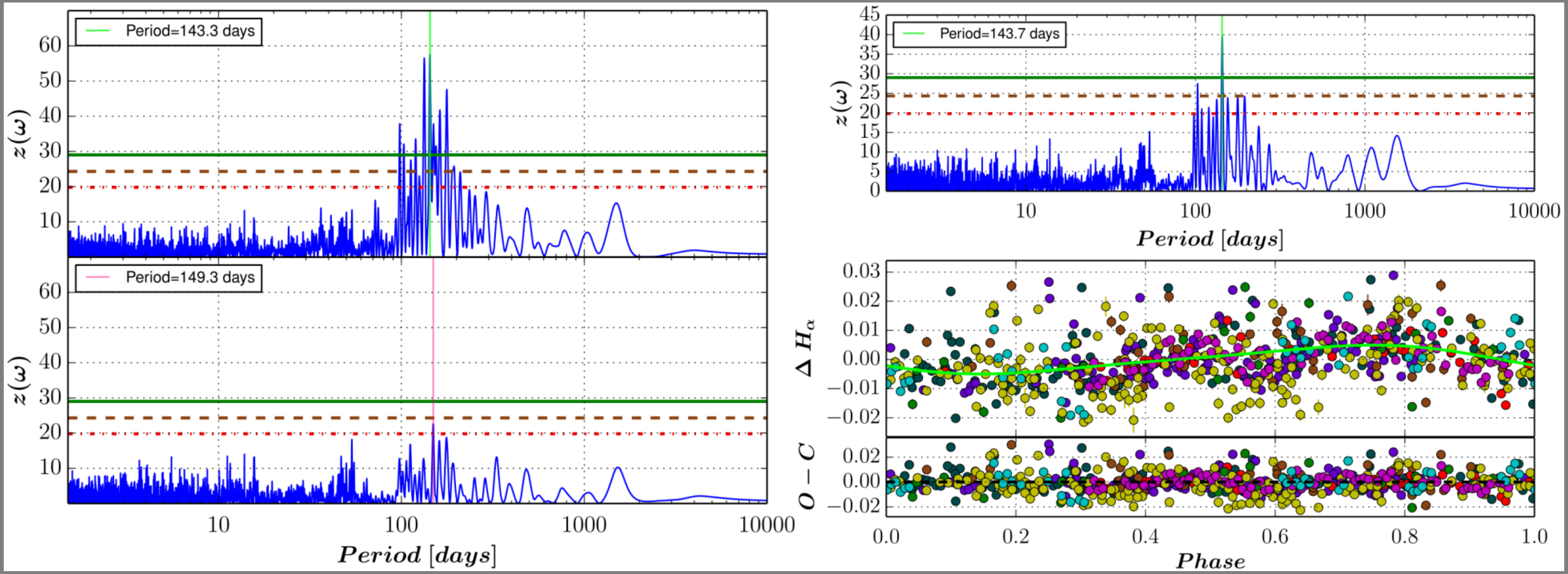

Hα | CaHK | NaD | FWHM | Photometry

- **Results:**
  - 348 measurements
    - <S>=4.63
    - Mean Error=0.06
    - RMS=0.6

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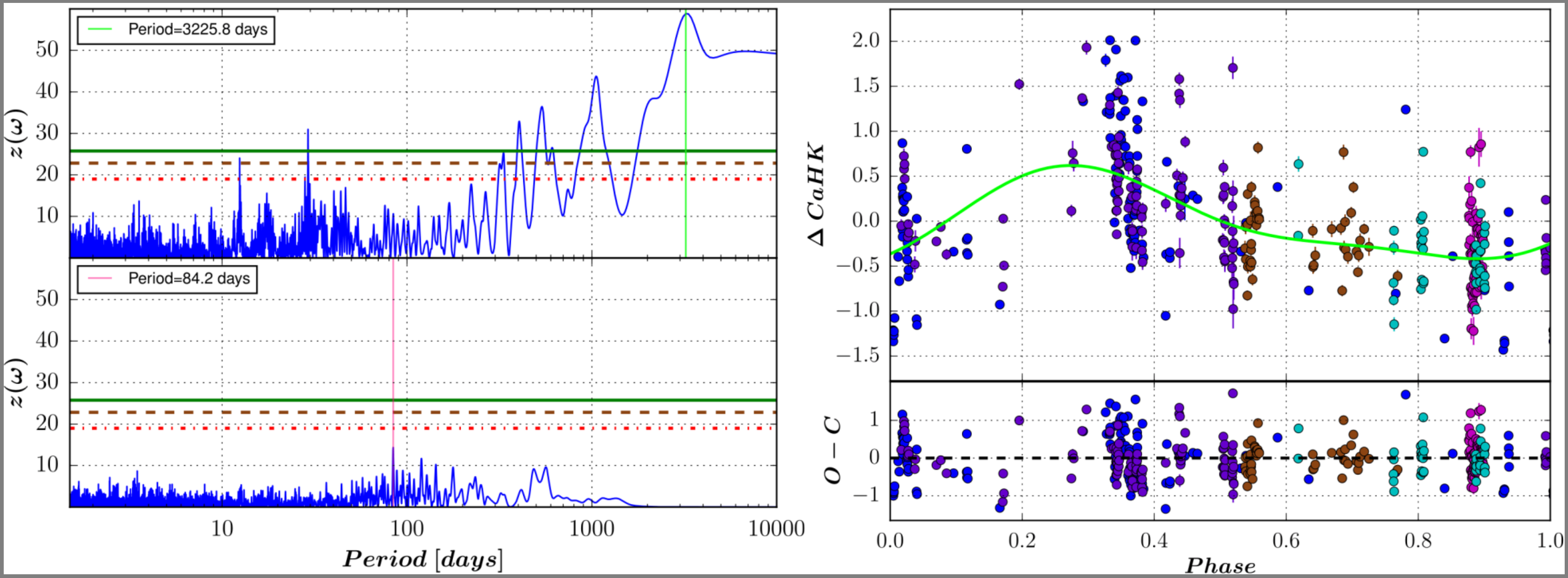

Hα | CaHK | NaD | FWHM | Photometry

- **Results:**
  - 448 measurements
    - <N>=0.19
    - Mean Error=0.01
    - RMS=0.02

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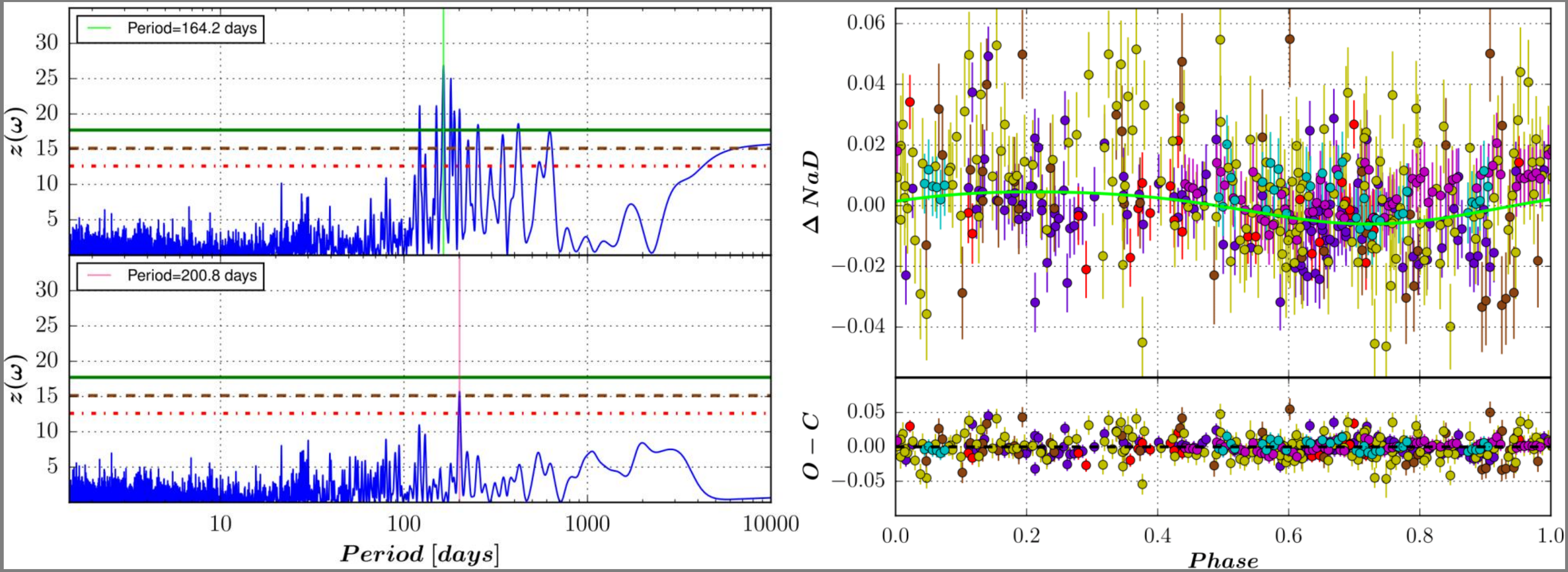

- **Results:**

  - 448 measurements
    - <N>=0.19
    - Mean Error=0.01
    - RMS=0.02
  - Differential Rotation
    - 40% in the Sun
      - 25 days in the equator
      - 35 days in the pole
    - 15% in Barnard
      - Comparing the Hα and NaD values

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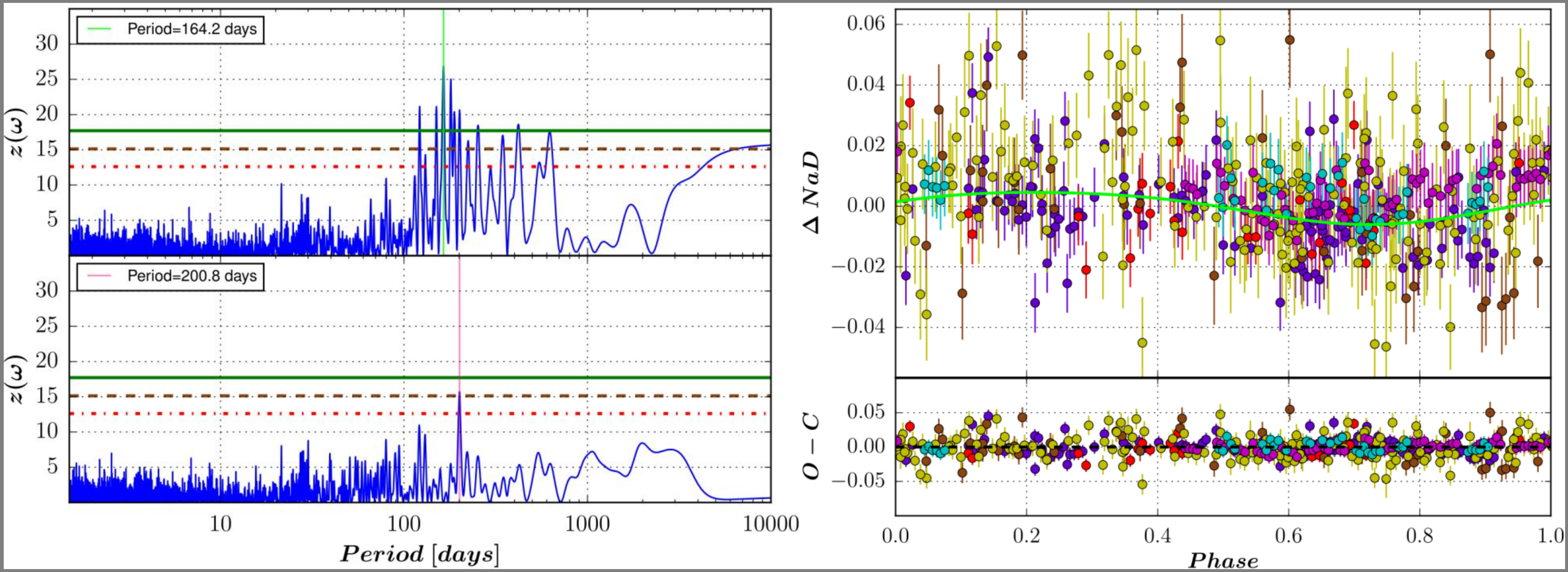

- **Results:**
  - 387 measurements
    - <FWHM>=4.52 km/s
    - Mean Error=0.0005 km/s
    - RMS=0.006 km/s

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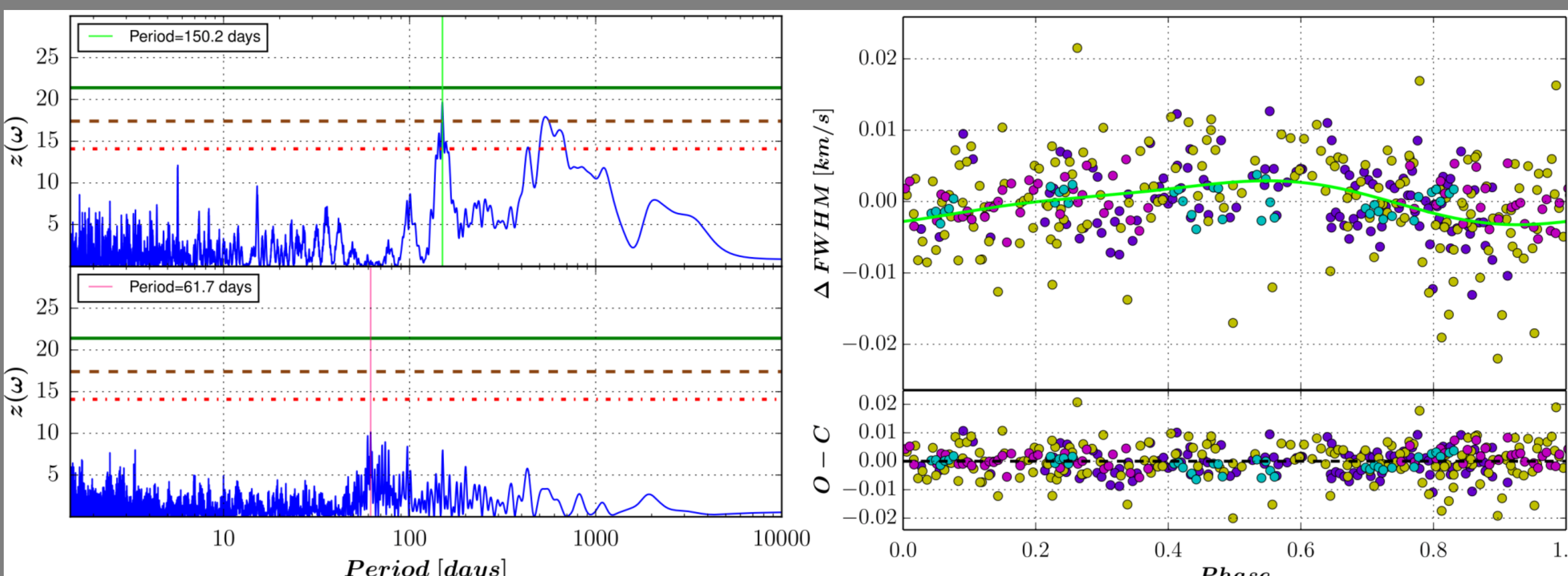

Hα | CaHK | NaD | FWHM | Photometry

- **Results:**

  - 1390 measurements

    - <V>=9.5 mag
    - Mean Error=9.2 mmag
    - RMS=15.4 mmag

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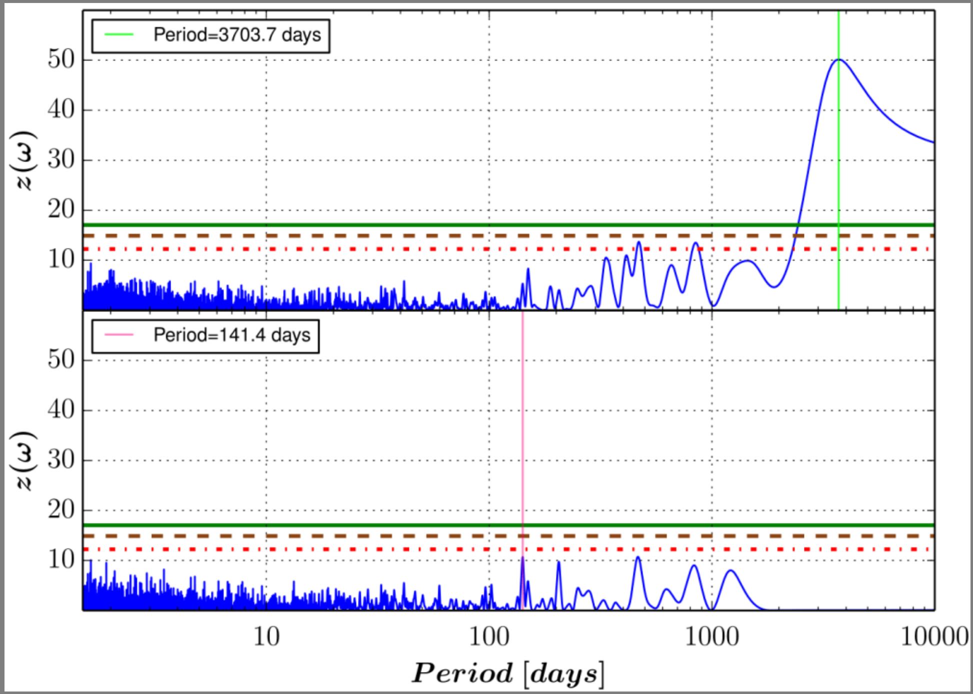

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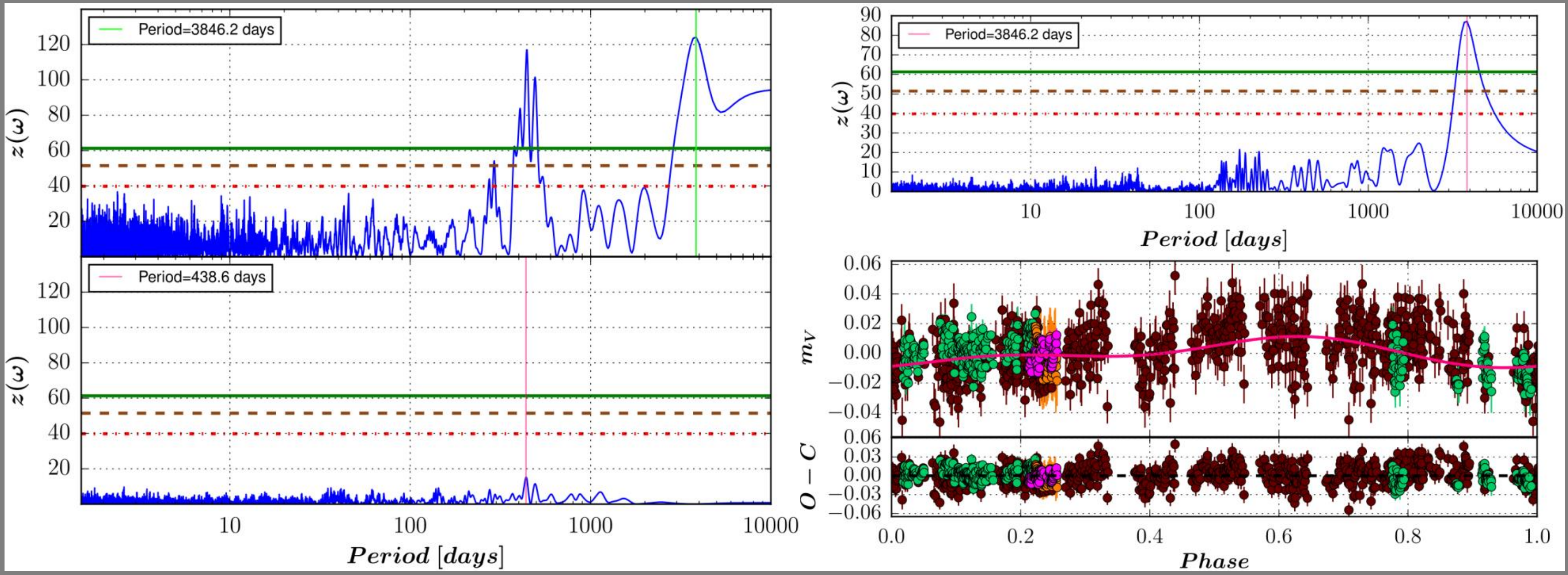
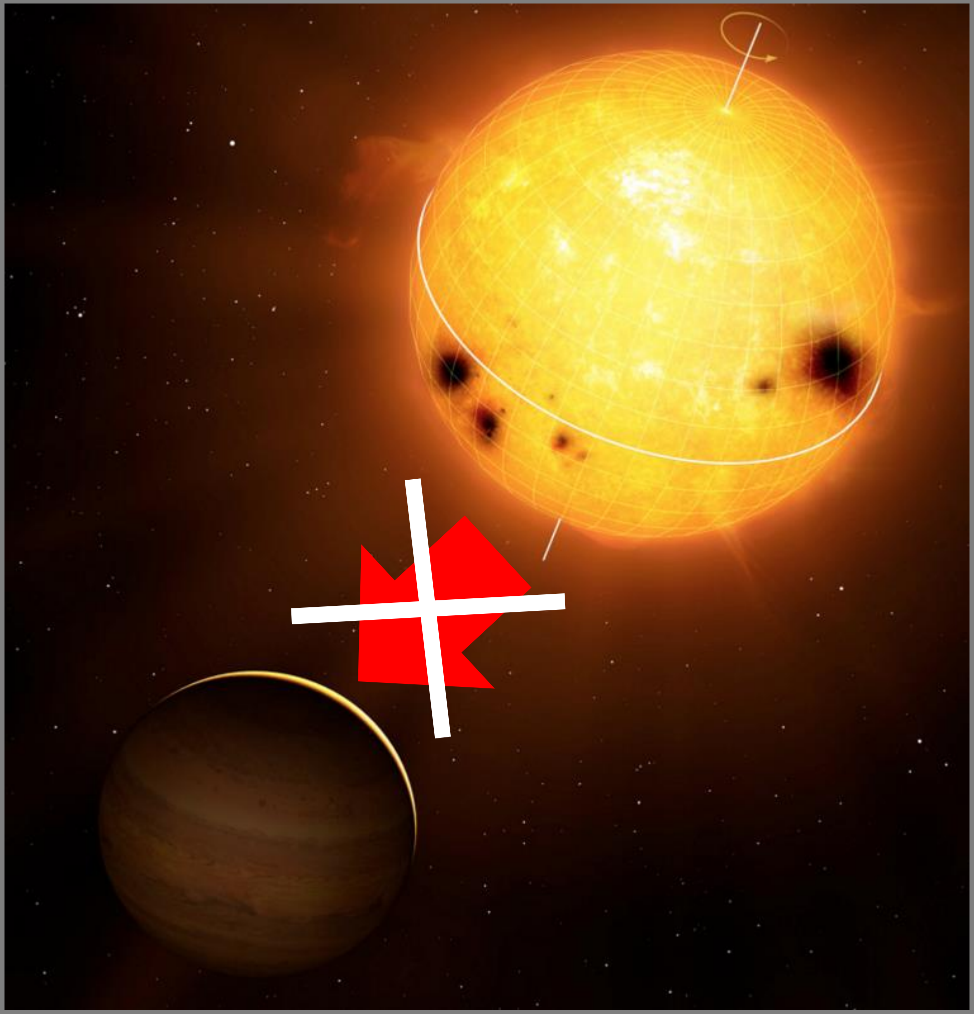
Toledo-Padrón+2018



CONCLUSIONS

- **Conclusions:** From all time-series:

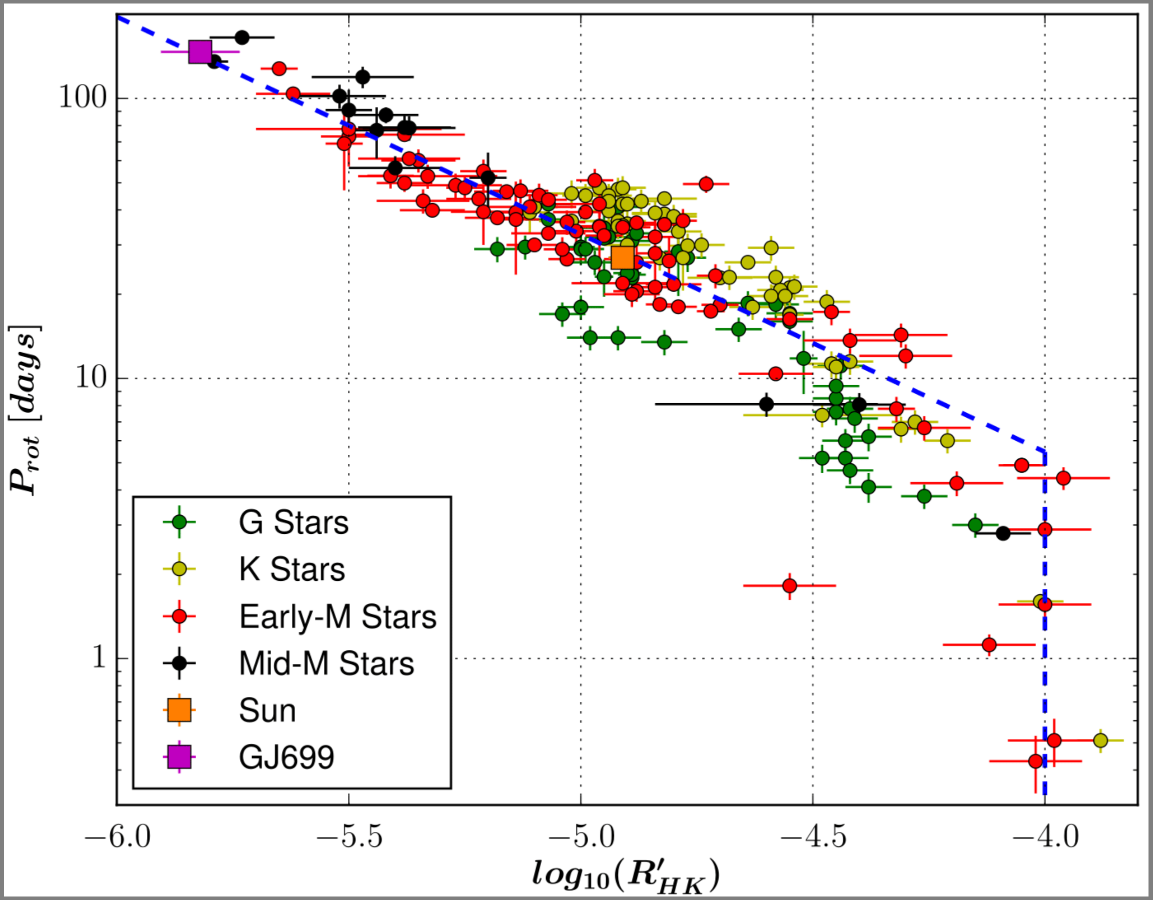
  - The 233-day period signal does not have a stellar activity origin.



Planet | **Rotation Period** | Long-term Cycle

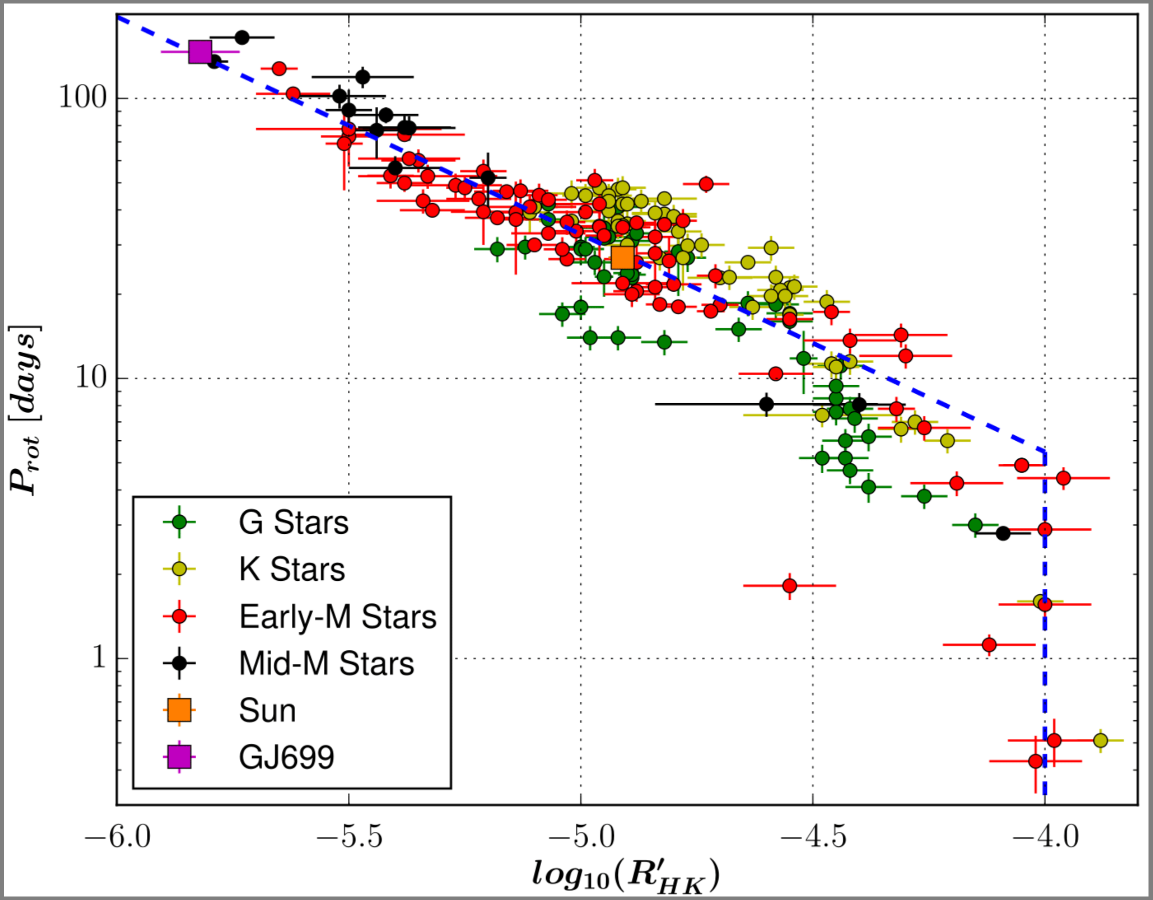
- **Conclusions:** From Hα, NaD and V-band photometry time-series:

  - $P_{rot} = 145 \pm 15\ days$



Toledo-Padrón+2018

- **Conclusions:** From Hα, NaD and V-band photometry time-series:
  - $P_{rot} = 145 \pm 15\ days$
  - Differential rotation between 130 and 180 days



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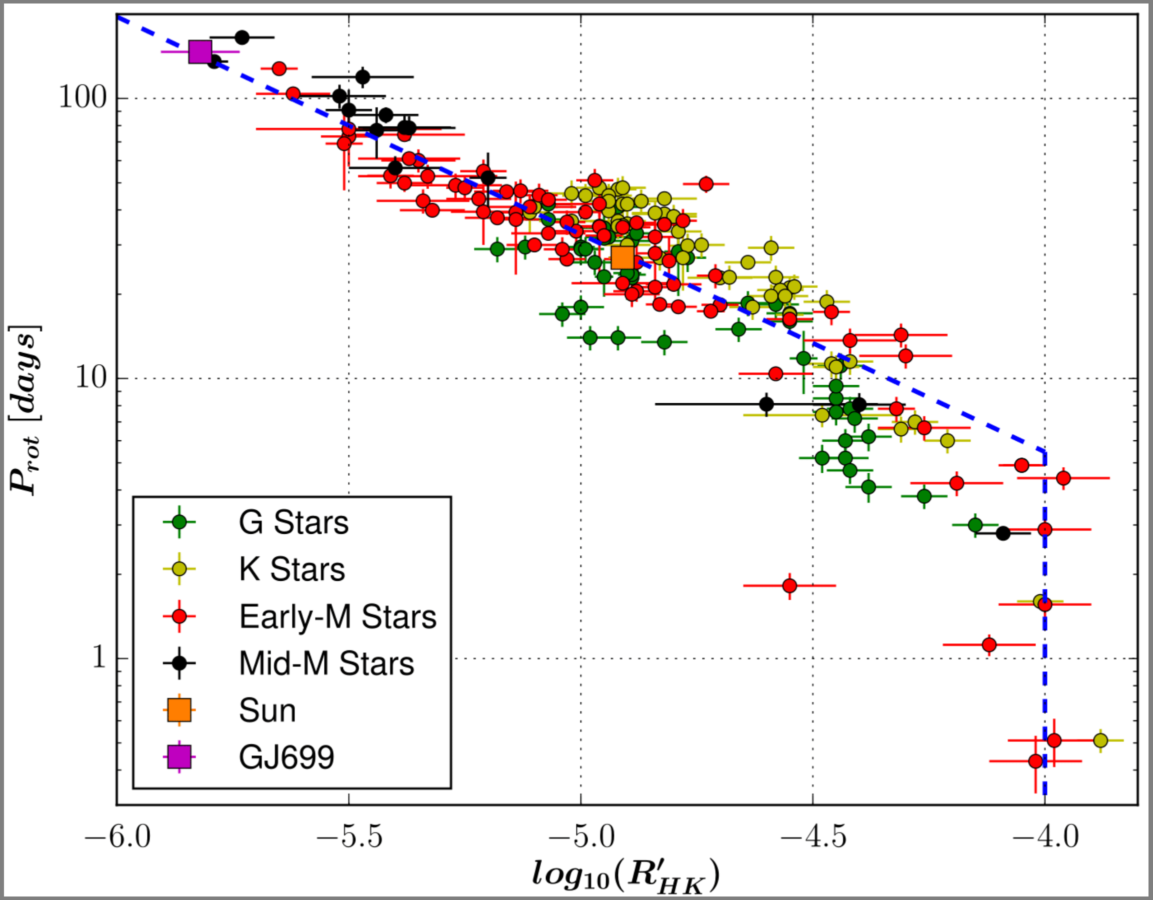
- **Conclusions:** From Hα, NaD and V-band photometry time-series:
  - $P_{rot} = 145 \pm 15\ days$
  - Differential rotation between 130 and 180 days
  - One of the lowest rotation known to date



Toledo-Padrón+2018

- **Conclusions:** From CaHK and V-band photometry time-series:

  - $Cycle = 10\ \pm 2\ years$

    - Not expected for a completely convective star like Barnard

Planet | Rotation Period | **Long-term Cycle**

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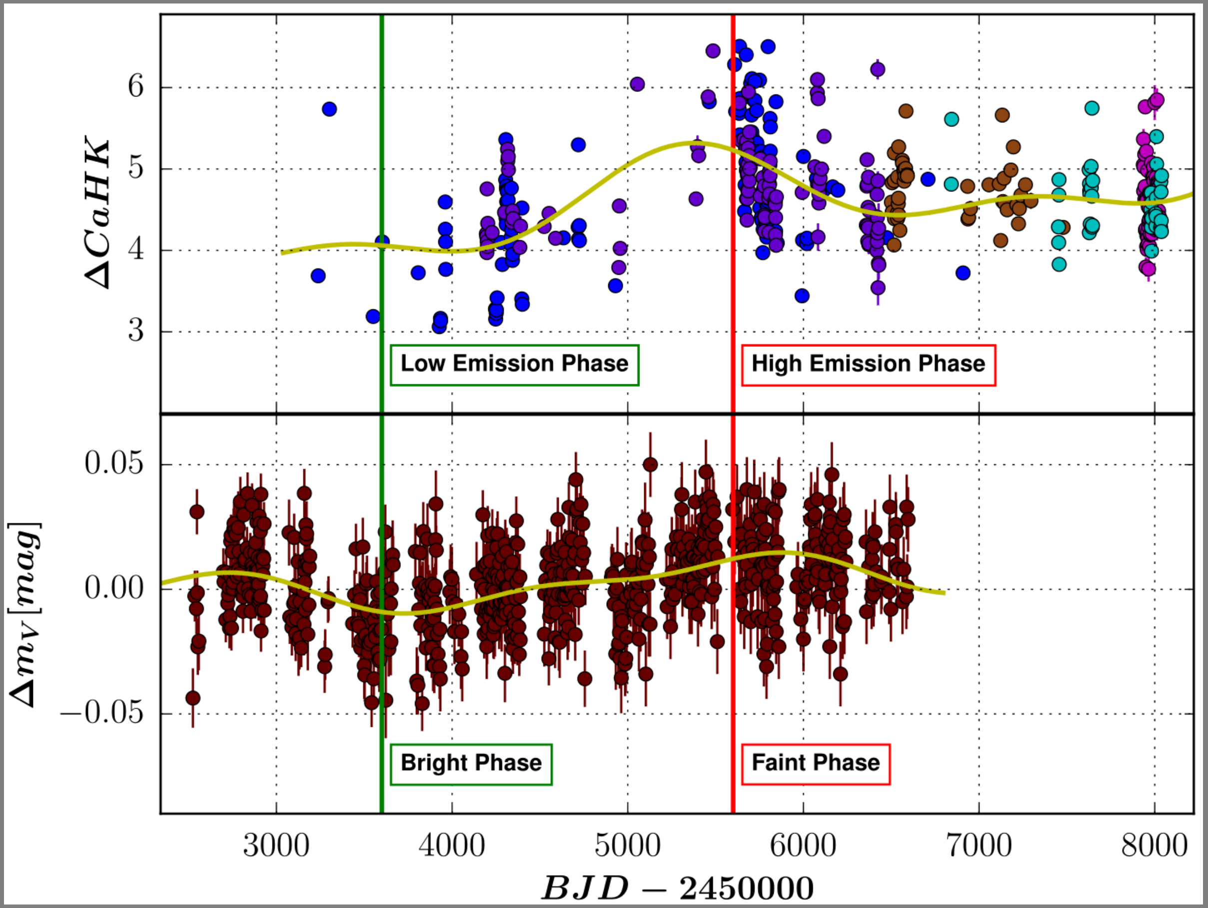
  - Opposite behavior from the Sun



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Planet | Rotation Period | **Long-term Cycle**

- **Conclusions:** From CaHK and V-band photometry time-series:
  - $Cycle = 10 \pm 2\ years$
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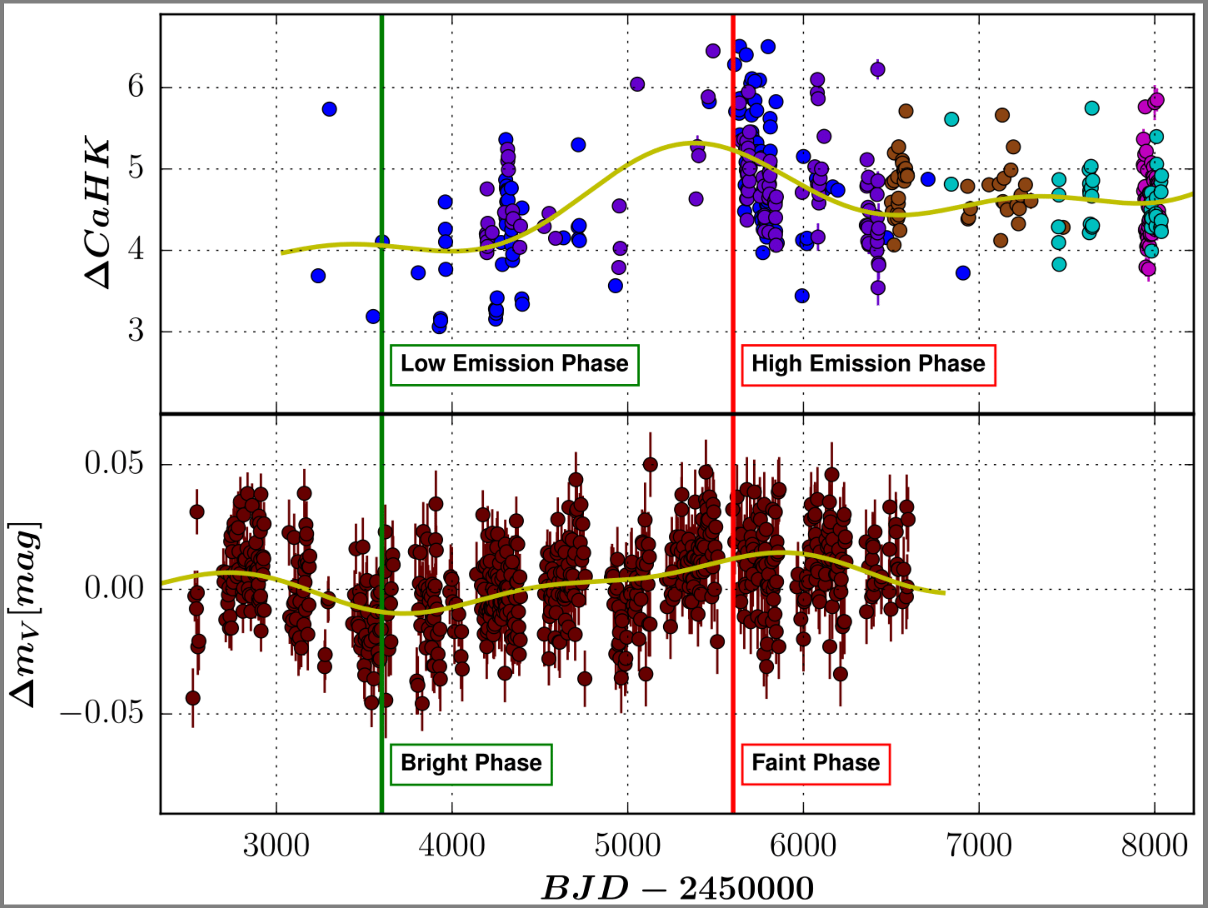
  - Opposite behavior from the Sun
  - Active FGK stars: Spot-dominated stellar surface
    1. Spot dominate brightness changes
    2. Plages dominate chromospheric and X-ray emission



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Planet | Rotation Period | **Long-term Cycle**

- **Conclusions:** From CaHK and V-band photometry time-series:
  - $Cycle = 10 \pm 2\ years$
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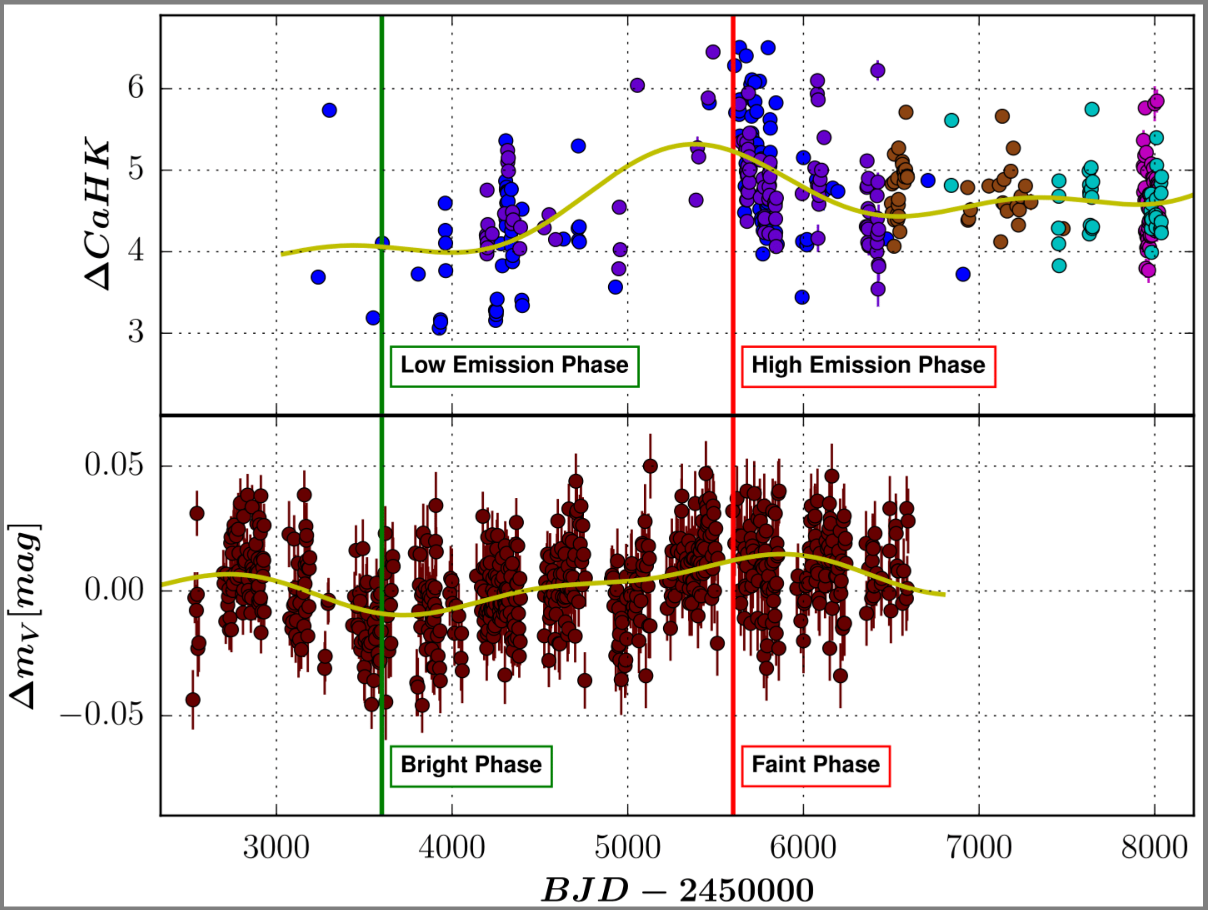
  - Opposite behavior from the Sun
  - Active FGK stars: Spot-dominated stellar surface
    1. Spot dominate brightness changes
    2. Plages dominate chromospheric and X-ray emission
  - Barnard's Star is not an 'active star



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THANK YOU
FOR YOUR ATTENTION