

# Search for Exoplanets around Northern Circumpolar Stars(SENS): Exoplanets and Stellar Pulsations and Rotations

Myeong-Gu Park  
Kyungpook National University  
&  
K-EXO

# 1. Exoplanet search in Korea

- Photometric methods
  - Eclipsing binary
  - Microlensing
  - Transit method
- Spectroscopic methods
  - Radial velocity measurement
    - Periodic RV variation from orbital motion
    - $v/c \sim 10^{-8}$

## 2. K-EXO Team

- Members
  - Byeong-Cheol Lee, Yeon-Ho Choi, Inwoo Han, Kang-Min Kim, Gwanghui Jeong (KASI)
  - MGP, Tae-Yang Bang (KNU)
  - Gennady Valyavin, Gazinur Galazutdinov (Russia), David E. Mkrtychian (Ukraine), Artie P. Hatzes (Germany)
  - Japanese & Chinese collaborators
- Exoplanets around bright F, G, K, M giants
  - Long period (100 ~ 1000 days) RV variations

### 3. BOES

- Bohyunsan Observatory Echelle Spectrograph
- Completed in 2002
- 1.8 m
  - Bright stars only
- 3,500 Å ~ 10,500 Å
- Spectral resolution  $R = 32000, 45000, 90000$
- Long-term rms scatter  $\sim 7 \text{ m s}^{-1}$

# BOES Configuration

한인우/이병철

CIM (Cassegrain Interface Module)



- Slit Monitoring System for A&G
- Calibration Lamp System
- Fiber output
- SPECTR/Long Slit Spectrograph

Spectrograph



- Fiber input
- Collimator
- Echelle grating & cross disperser
- Camera & CCD

## 5. Search for Exoplanets around Northern circumpolar Stars (SENS)

- Exoplanet search around F, G, K, M giants
  - Long period (100 ~ 1000 days) RV variations
- All-year round observations
  - Easy scheduling
  - No aliasing from seasonal variations

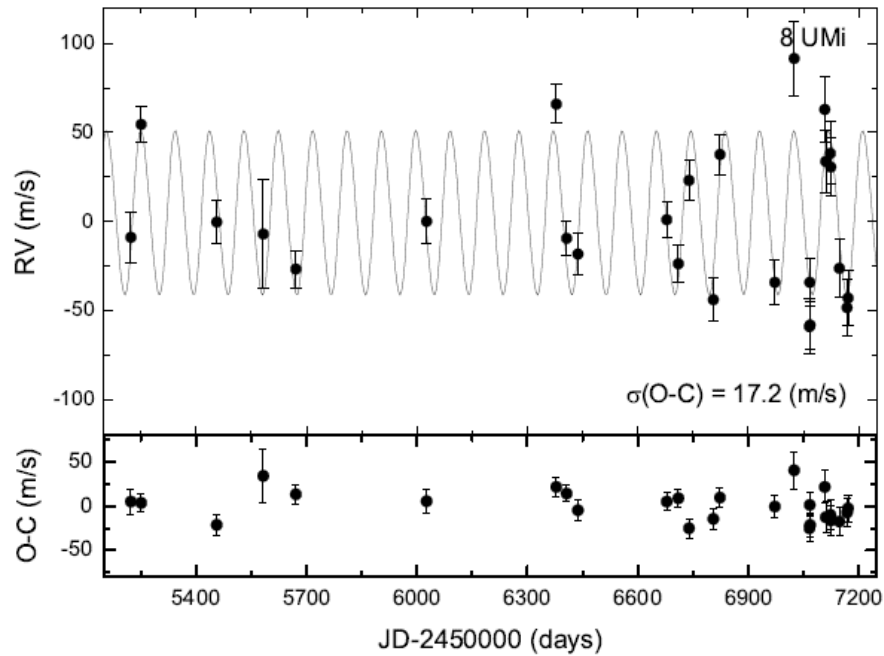
# Exoplanets from BOES

	Program	Duration	Sample	Exoplanets	Candidates
1	K giant	2003-2018	~50	11	1
2	F,M giant	2003-2019	~20	0	1
3	G giant	2005-?	188	2	~10
4	K dwarf	2008-2013	40	2	0
5	Binary	2010-2019	9	0	1
6	<b>SENS* I</b>	2010-2018	~220	20	~10
7	<b>SENS* II</b>	2017-2021	200	0	?
Total			700<	35	~23

~ Aug. 2023

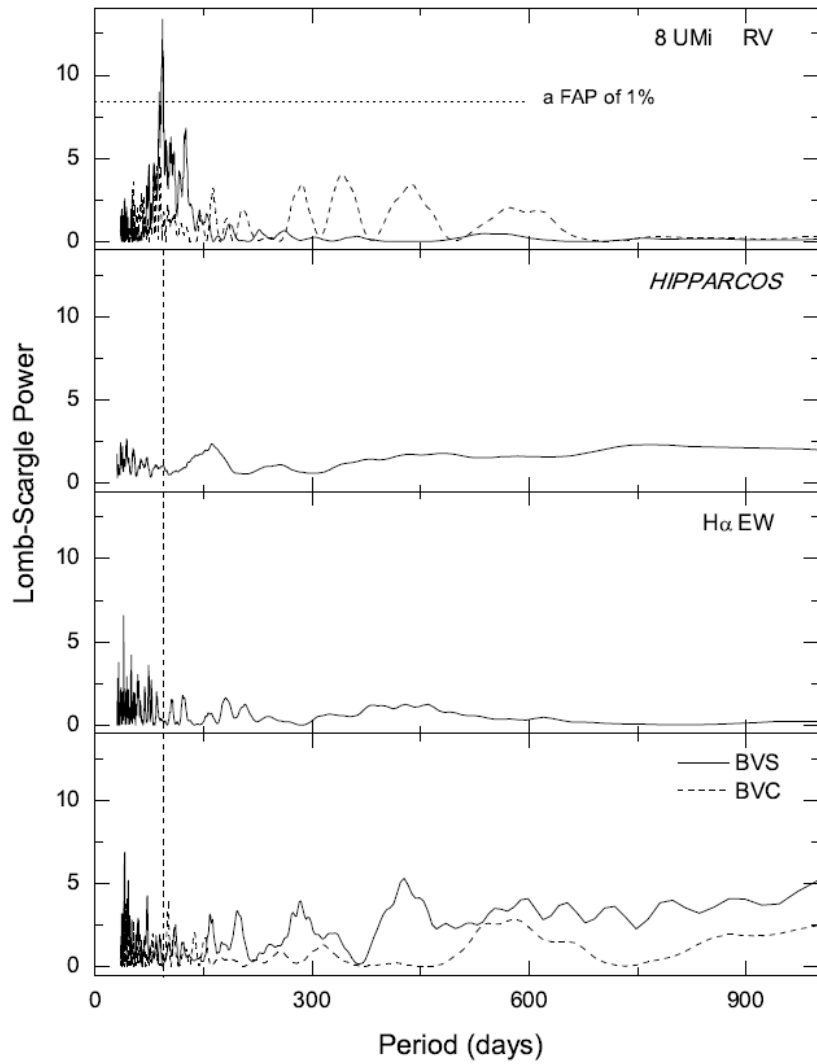
# 6. 8 Ursae Minoris

- Observation
  - Jan. 2010 ~ May 2015

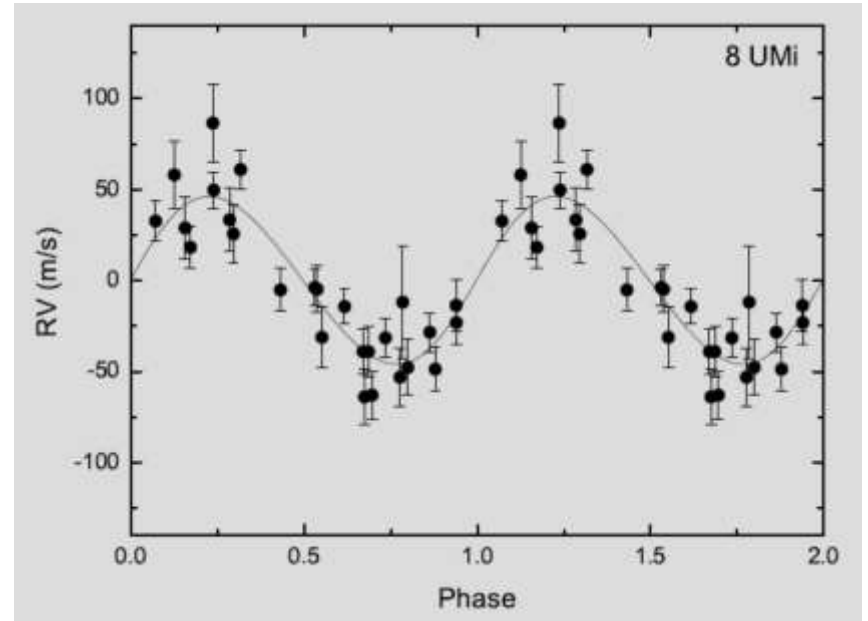


Time series





Periodogram



Phase curve

- Stellar parameters and orbital fit

Parameters	8 UMi
$\alpha$ (J2000)	14 56 48.353
$\delta$ (J2000)	+74 54 03.34
Spectral type	K0
$m_v$ (mag)	6.83
HIPPARCOS <sub>scat</sub> (mag)	0.008
$B - V$ (mag)	$0.985 \pm 0.010$
Parallax (mas)	$6.25 \pm 0.43$
Distance (pc)	$159.1 \pm 11.0$
Age (Gyr)	$1.7 \pm 0.2$
$T_{\text{eff}}$ (K)	$4847.4 \pm 7.5$
[Fe/H]	$-0.03 \pm 0.02$
$\log g$	$2.57 \pm 0.03$
$R_{\star}$ ( $R_{\odot}$ )	$9.9 \pm 0.4$
$M_{\star}$ ( $M_{\odot}$ )	$1.8 \pm 0.1$
$L_{\star}$ [ $L_{\odot}$ ]	55.94
$v_{\text{rot}} \sin i$ ( $\text{km s}^{-1}$ )	3.6
$P_{\text{rot}}/\sin i$ (days)	139.1
$v_{\text{micro}}$ ( $\text{km s}^{-1}$ )	$1.48 \pm 0.04$

Parameter	8 UMi b
$P$ (days)	$93.4 \pm 4.5$
$T_{\text{periastron}}$ (JD)	$2\,454\,108.5 \pm 22.8$
$K$ ( $\text{m s}^{-1}$ )	$46.1 \pm 4.0$
$e$	$0.06 \pm 0.18$
$\omega$ (deg)	$91.0 \pm 84.6$
$m \sin i$ ( $M_{\text{Jup}}$ )	$1.5 \pm 0.2$
$a$ (AU)	$0.49 \pm 0.03$
$N_{\text{obs}}$	26
rms ( $\text{m s}^{-1}$ )	17.2

## Search for exoplanet around northern circumpolar stars

### Four planets around HD 11755, HD 12648, HD 24064, and 8 Ursae Minoris<sup>★</sup>

B.-C. Lee (이병철)<sup>1,2</sup>, M.-G. Park (박명구)<sup>3</sup>, S.-M. Lee (이상민)<sup>1</sup>, G. Jeong (정광희)<sup>1,2</sup>, H.-I. Oh (오형일)<sup>3</sup>,  
I. Han (한인우)<sup>1</sup>, J. W. Lee (이재우)<sup>1</sup>, C.-U. Lee (이충욱)<sup>1</sup>,  
S.-L. Kim (김승리)<sup>1</sup>, and K.-M. Kim (김강민)<sup>1</sup>

<sup>1</sup> Korea Astronomy and Space Science Institute, 776, Daedeokdae-Ro, Youseong-Gu, 305-348 Daejeon, Korea  
e-mail: bclee@kasi.re.kr

<sup>2</sup> Korea University of Science and Technology, Gajeong-ro Yuseong-gu, 305-333 Daejeon, Korea

<sup>3</sup> Department of Astronomy and Atmospheric Sciences, Kyungpook National University, 702-701 Daegu, Korea

Received 29 July 2015 / Accepted 24 September 2015

#### ABSTRACT

*Aims.* This program originated as the north pole region extension of the established exoplanet survey using the 1.8 m telescope at Bohyunsan Optical Astronomy Observatory (BOAO). The aim of our paper is to find exoplanets in northern circumpolar stars with a precise radial velocity (RV) survey.

*Methods.* We selected about 200 northern circumpolar stars with the following criteria:  $\delta \geq 70^\circ$ ,  $0.6 < B - V < 1.6$ ,  $\text{HIPPARCOS}_{\text{cut}} < 0.05$  mag, and  $5.0 < m_p < 7.0$ . The high-resolution, fiber-fed Bohyunsan Observatory Echelle Spectrograph (BOES) was used for the RV survey. Chromospheric activities, the HIPPARCOS photometry, and line bisectors were analyzed to exclude other causes for the RV variations.

*Results.* In 2010, we started to monitor the candidates and have completed initial screening for all stars for the past five years. We present the detection of four new exoplanets. Stars HD 11755, HD 12648, HD 24064, and 8 UMi all show evidence of giant planets in Keplerian motion. The companion to HD 11755 has a minimum mass of  $6.5 M_{\text{Jup}}$  in a 433-day orbit with an eccentricity of 0.19. HD 12648 is orbited by a companion with a minimum mass of  $2.9 M_{\text{Jup}}$ , a period of 133 days, and an eccentricity of 0.04. Weak surface activity was suspected in HD 24064. However, no evidence was found to be associated with the RV variations. Its companion has a minimum mass of  $9.4 M_{\text{Jup}}$ , a period of 535 days, and an eccentricity of 0.35. Finally, 8 UMi has a minimum mass of  $1.5 M_{\text{Jup}}$  and a period of 93 days with an eccentricity of 0.06.



# NameExoWorlds

A global project in celebration of 100 years of IAU

Names will be chosen by public  
voting carried out in each country.

IAU100 Global Partners



Project Partners



2019

# SOUTH KOREA



IAU 100  
NameExoWorld

## NATIONAL CAMPAIGN OVERVIEW

Number of proposals received in the country:

**325**

Number of votes received in the country:

**2748**

## CHARACTERISTICS OF SYSTEM

Constellation:

**Ursa Minor**

Star Identification:

**8 UMI**

Host star type:

**yellow, giant**

Coordinates:

**RA 14h56m48.35s**  
**DEC +74d54m03.3s**

## RESULTS

Name of Star:

**Baekdu**

Brief explanation Name Star:

Baekdu is the highest mountain on the Korean peninsula, situated in North Korea, and symbolises the national spirit of Korea.

Name of Exoplanet:

**Halla**

Brief Explanation Name of Exoplanet:

Halla is the highest mountain in South Korea and is regarded as a sacred place in the region.

## THEME

Sacred peaks of Korea and symbols of peace and spirituality among the Korean people.



- Hon+ (2023) Nature

## A close-in giant planet escapes engulfment by its star

<https://doi.org/10.1038/s41586-023-06029-0>

Received: 12 August 2022

Accepted: 28 March 2023

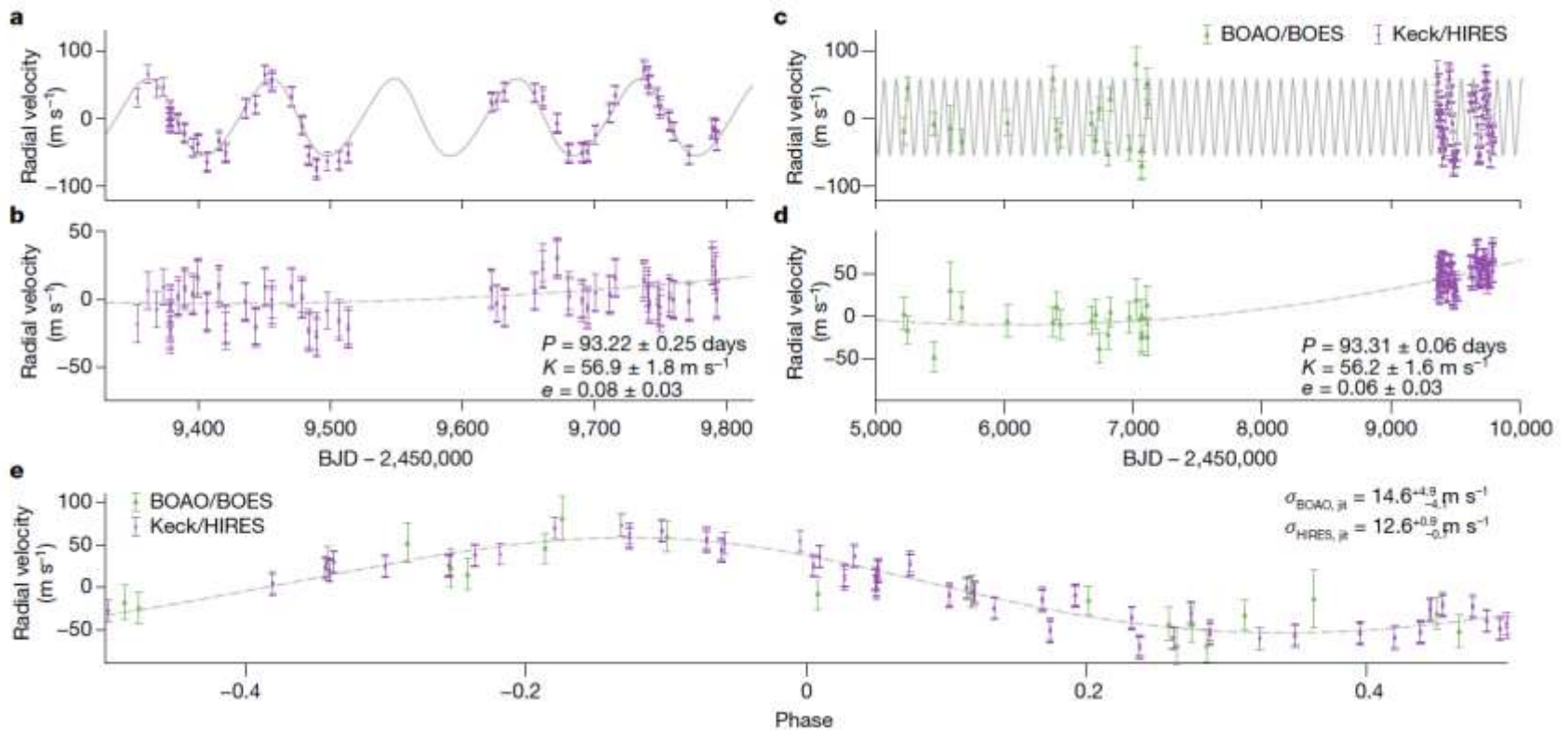
Published online: 28 June 2023

 Check for updates

Marc Hon<sup>1</sup>✉, Daniel Huber<sup>1,2</sup>, Nicholas Z. Rui<sup>3</sup>, Jim Fuller<sup>3</sup>, Dimitri Veras<sup>4,5,6</sup>, James S. Kuzlewicz<sup>7,8</sup>, Oleg Kochukhov<sup>9</sup>, Amalie Stokholm<sup>8,10,11</sup>, Jakob Lysgaard Rorsted<sup>8</sup>, Mutlu Yıldız<sup>12</sup>, Zeynep Çelik Orhan<sup>12</sup>, Sibel Örtel<sup>12</sup>, Chen Jiang<sup>13</sup>, Daniel R. Hey<sup>1</sup>, Howard Isaacson<sup>14</sup>, Jingwen Zhang<sup>1</sup>, Mathieu Vrad<sup>15</sup>, Keivan G. Stassun<sup>16</sup>, Benjamin J. Shappee<sup>1</sup>, Jamie Tayar<sup>1,17</sup>, Zachary R. Clayton<sup>1,17</sup>, Corey Beard<sup>18</sup>, Timothy R. Bedding<sup>2</sup>, Casey Brinkman<sup>1</sup>, Tiago L. Campante<sup>19,20</sup>, William J. Chaplin<sup>21</sup>, Ashley Chontos<sup>1,22</sup>, Steven Giacalone<sup>13</sup>, Rae Holcomb<sup>17</sup>, Andrew W. Howard<sup>23</sup>, Jack Lubin<sup>17</sup>, Mason MacDougall<sup>24</sup>, Benjamin T. Montet<sup>25,26,27</sup>, Joseph M. A. Murphy<sup>28</sup>, Joel Ong<sup>1,29</sup>, Daria Pidhorodetska<sup>30</sup>, Alex S. Polanski<sup>31</sup>, Malena Rice<sup>29,32</sup>, Dennis Stello<sup>2,28,33</sup>, Dakotah Tyler<sup>24</sup>, Judah Van Zandt<sup>24</sup> & Lauren M. Weiss<sup>34</sup>

The red giant 8 Ursae Minoris (8 UMi; also known as Baekdu), was discovered to host the giant planet 8 Ursae Minoris b (8 UMi b; also known as Halla) on a close-in, near-zero eccentricity ( $e \approx 0.06$ ) orbit with a period of  $93.4 \pm 4.5$  days on the basis of observations from the Bohyunsan Optical Astronomy Observatory (BOAO)<sup>10</sup>. The detec-

– 135 RV observations with HIRES on Keck-I



## – Keplerian fit

<b>Orbital parameters</b>	
Orbital period, $P$	$93.31 \pm 0.06$ days
Radial velocity semi-amplitude, $K$	$56.1^{+1.7}_{-1.6}$ $\text{ms}^{-1}$
Eccentricity, $e$	$0.062^{+0.028}_{-0.030}$
Argument of periastron, $\omega$	$0.942^{+0.533}_{-0.463}$ rad
Time of periastron passage (BJD), $t_p$	$2457601.379^{+7.844}_{-6.936}$
<b>Instrumental parameters</b>	
BOAO/BOES centre of mass velocity, $\gamma_{\text{BOES}}$	$13.33^{+7.42}_{-7.49}$ $\text{ms}^{-1}$
Keck/HIRES centre of mass velocity, $\gamma_{\text{HIRES}}$	$-46.91 \pm 11.92$ $\text{ms}^{-1}$
BOAO/BOES jitter, $\sigma_{\text{BOES}}$	$14.59^{+4.89}_{-4.12}$ $\text{ms}^{-1}$
Keck/HIRES jitter, $\sigma_{\text{HIRES}}$	$12.65^{+0.86}_{-0.75}$ $\text{ms}^{-1}$
Linear acceleration, $\dot{\gamma}$	$0.014 \pm 0.005$ $\text{ms}^{-1} \text{day}^{-1}$
Curvature, $\ddot{\gamma}$ ( $\times 10^{-5}$ )	$0.49 \pm 0.15$ $\text{ms}^{-1} \text{day}^{-2}$
<b>Derived parameters</b>	
Planet mass, $M_p \sin i$	<u><math>1.65 \pm 0.06 M_J</math></u>
Planet semi-major axis, $a_{\text{pl}}$	<u><math>0.462 \pm 0.006</math> AU</u>

The median values of the posterior distribution are reported. The lower- and upper-bound uncertainties are the intervals between the median with the 16th and 84th percentile values of the distribution, respectively. BOES, Bohyunsan Observatory Echelle Spectrograph.; BJD, barycentric Julian date.

Parameter	8 UMi b
$P$ (days)	$93.4 \pm 4.5$
$T_{\text{periastron}}$ (JD)	$2\,454\,108.5 \pm 22.8$
$K$ ( $\text{m s}^{-1}$ )	$46.1 \pm 4.0$
$e$	$0.06 \pm 0.18$
$\omega$ (deg)	$91.0 \pm 84.6$
$m \sin i$ ( $M_{\text{Jup}}$ )	<u><math>1.5 \pm 0.2</math></u>
$a$ (AU)	<u><math>0.49 \pm 0.03</math></u>
$N_{\text{obs}}$	26
rms ( $\text{m s}^{-1}$ )	17.2

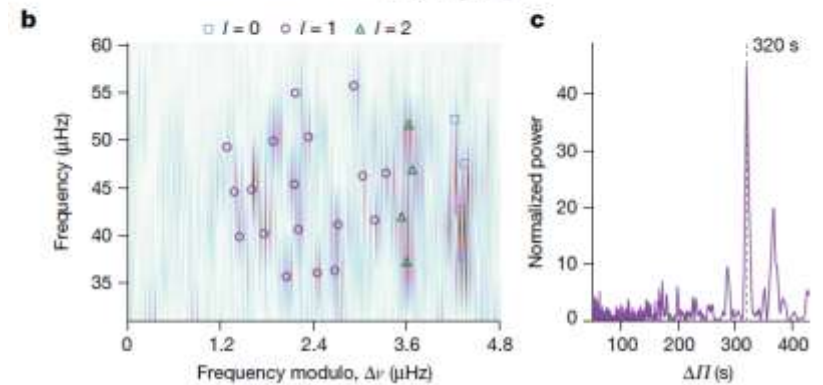
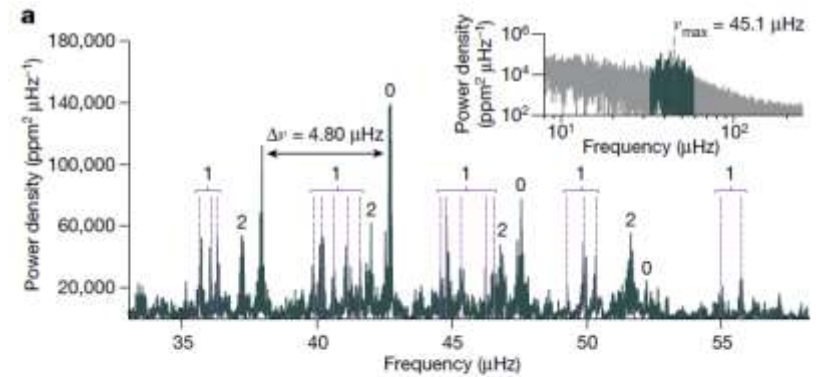
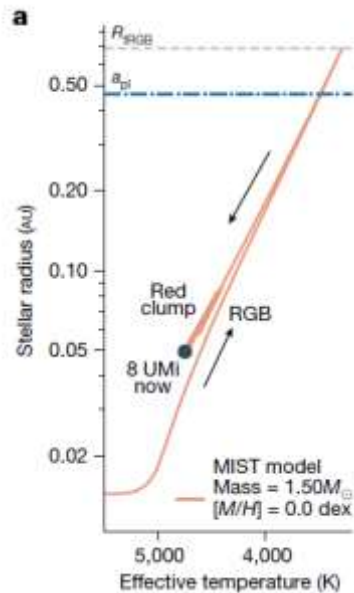


– TESS photometry

- Two 6 months data

– Asteroseismology

- Measured  $\Delta\Pi \approx 320\text{s}$
- Core-helium burning red giant:  $\Delta\Pi \sim 250 - 400\text{s}$



– Star mass

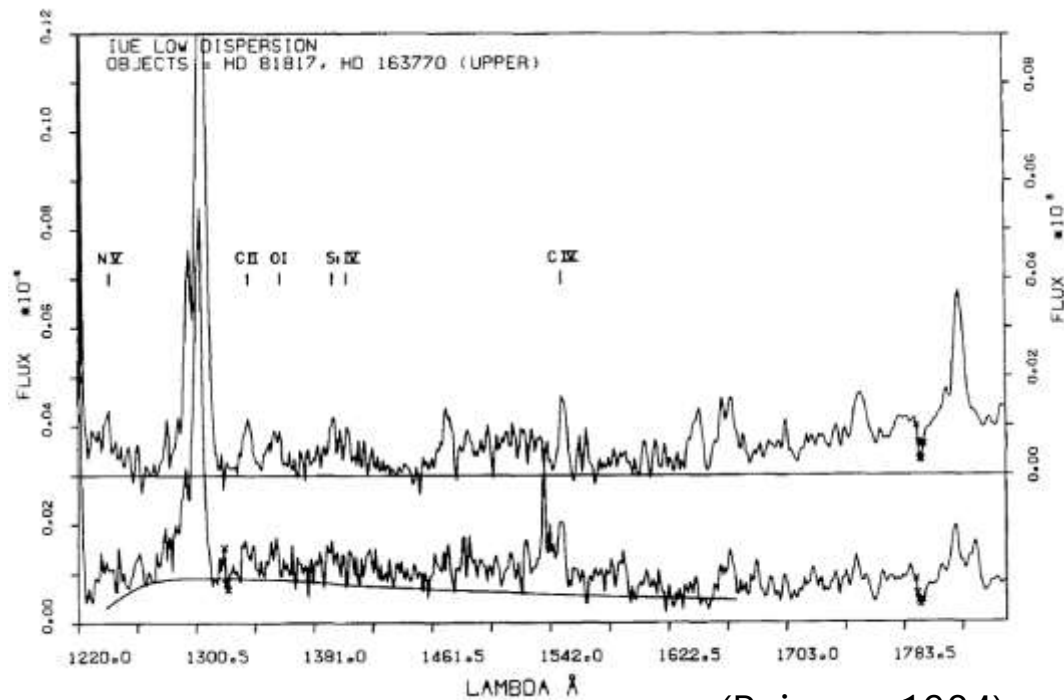
- Spectroscopy
- Asteroseismology
- $M_* = 1.51 \pm 0.05 M_{\odot}$   
 $\Rightarrow a = 0.462 \pm 0.006$  AU

– Puzzle

- Stellar evolution predicts 8 Umi would have once expanded to about **0.7 AU**.
- Host star > current orbital distance of 8 Umi b

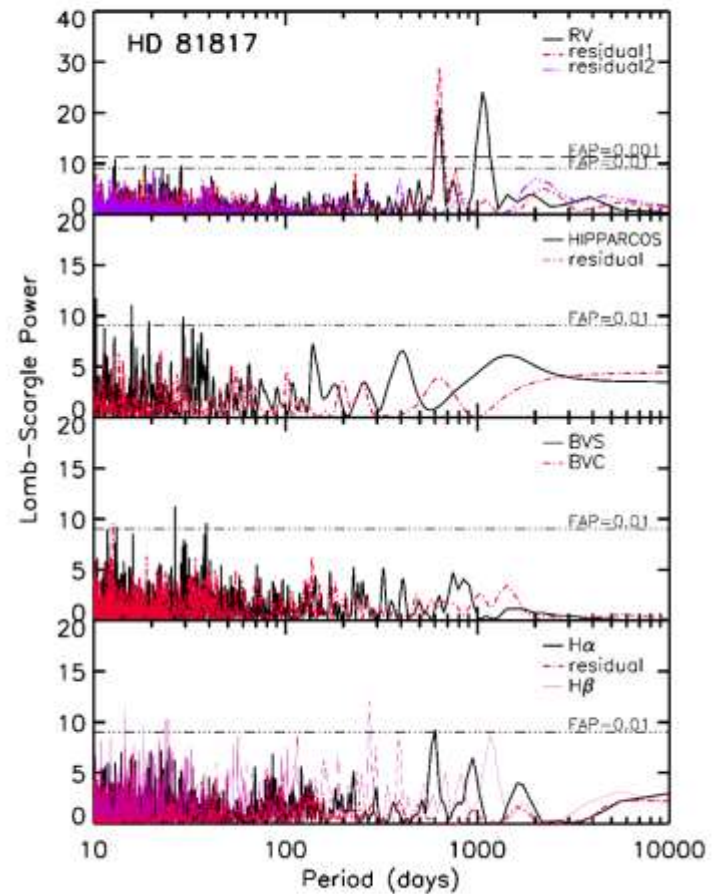
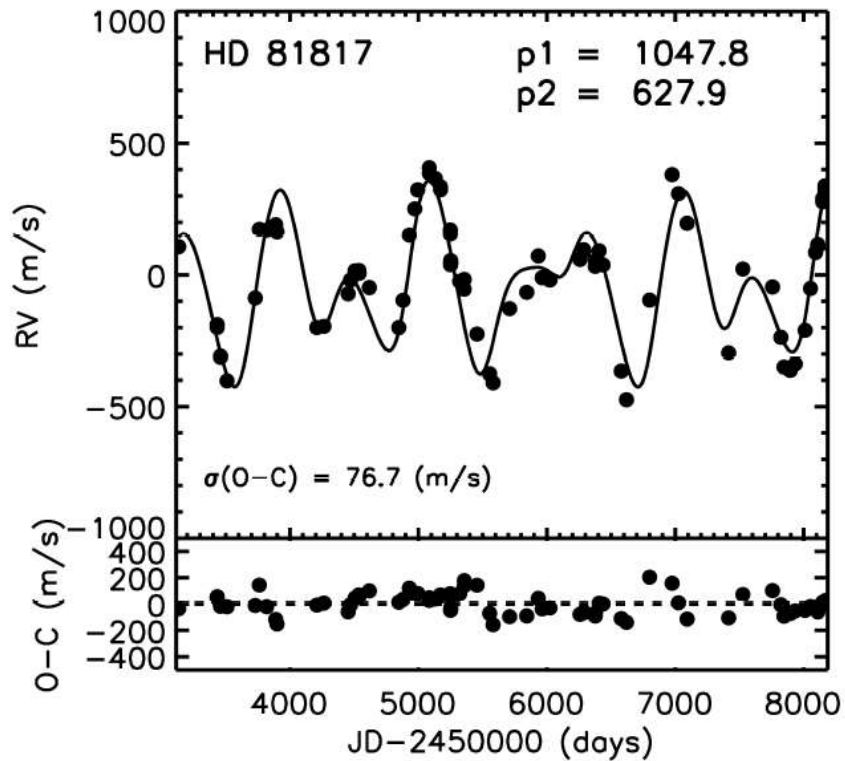
# 7. HD 81817

- Hybrid star
  - Cool stellar wind feature with emission features in UV or in X-ray

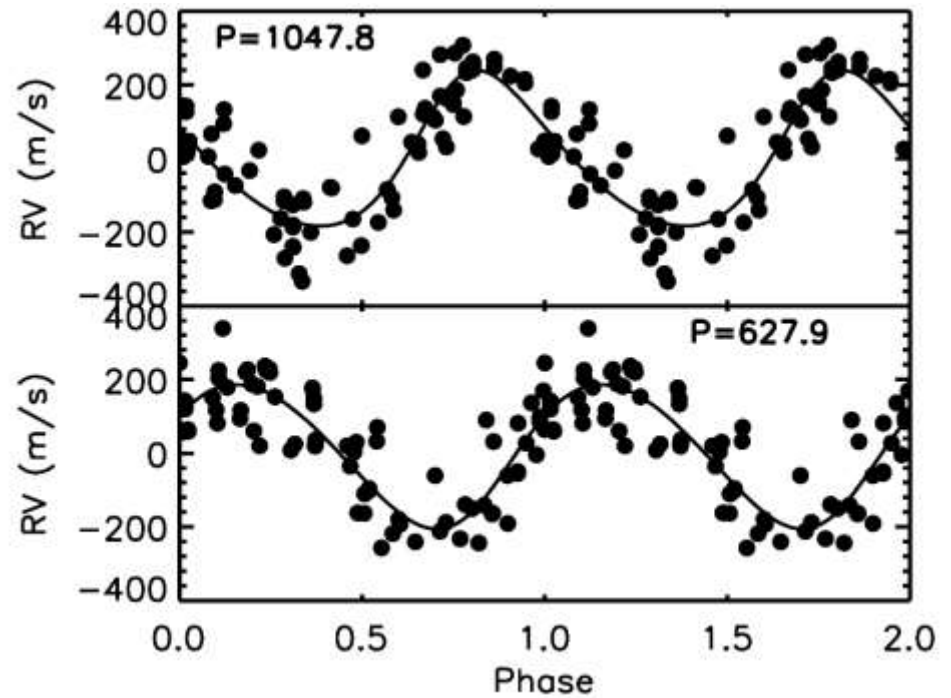


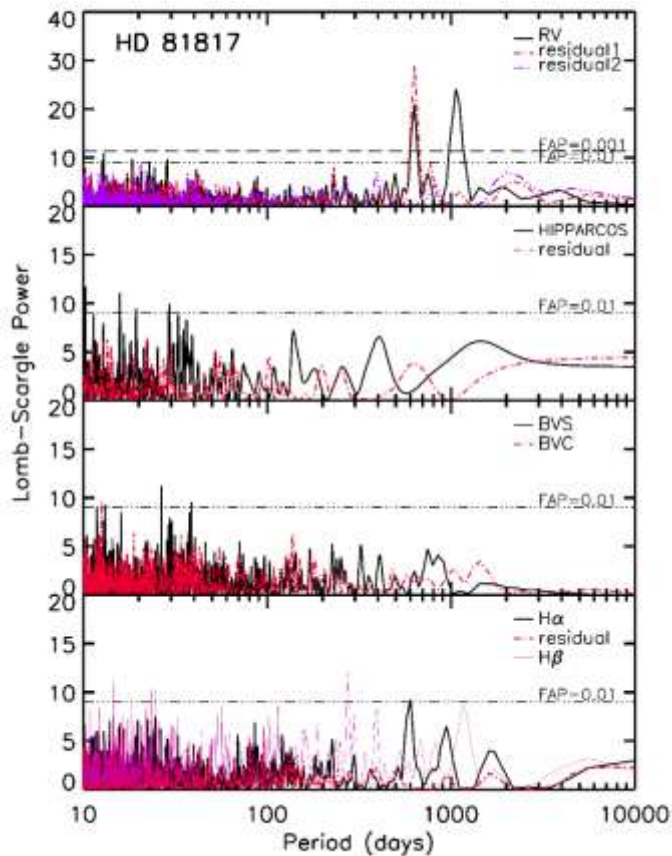
(Reimers 1984)

- 2004 ~ 2018, 84 spectra



- RV amplitude is too small for WD companion.
- Periodic variations in RV
  - P1 = 1047.8 days
  - P2 = 627.9 days





## Keplerian fit

Parameter		HD 81817 b
P	[days]	$1047.8 \pm 8.5$
$T_{\text{periastron}}$	[JD]	$2449712 \pm 108$
$K$	$[\text{m s}^{-1}]$	$211.4 \pm 16.4$
$e$		$0.17 \pm 0.07$
$\omega$	[deg]	$320 \pm 34$
$m \sin i$	$[\text{M}_{\text{Jup}}]$	$27.6 \pm 2.1$
$a$	[AU]	$3.3 \pm 0.1$
rms	$[\text{m s}^{-1}]$	76.7

In brown dwarf desert!

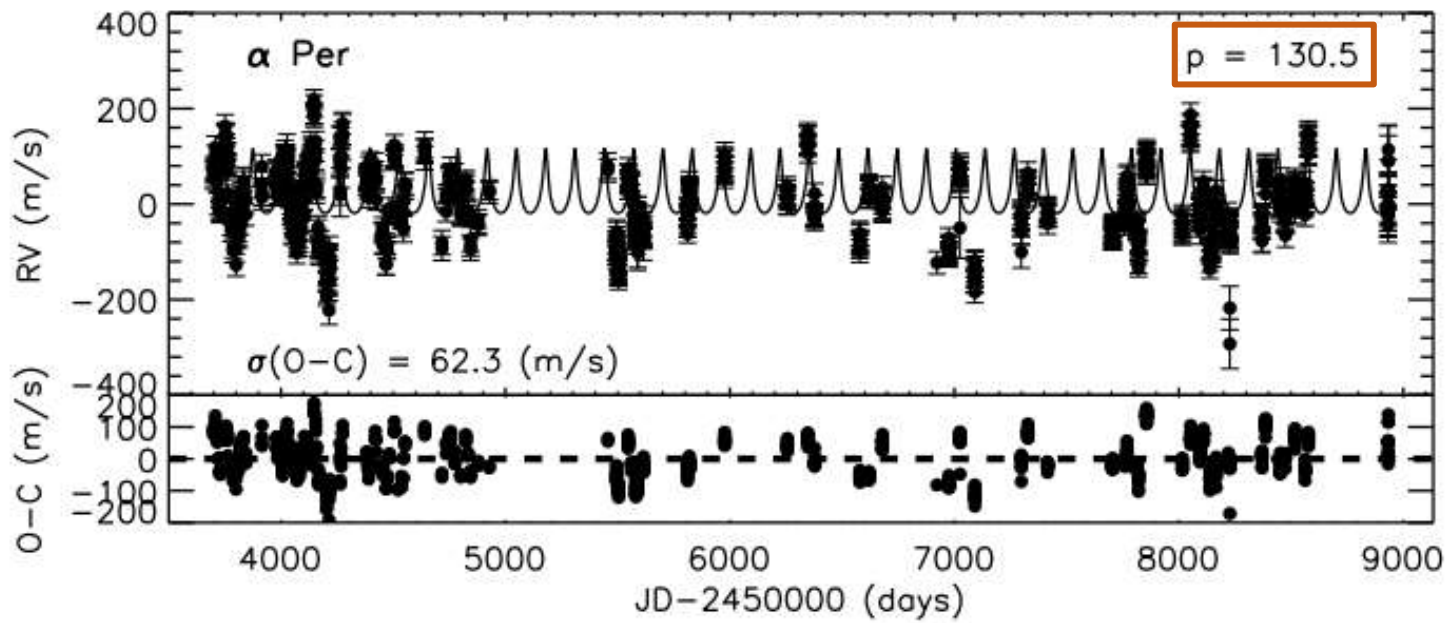
## 8. $\alpha$ Persei

- Mirfak
- F-type supergiant
  - $1.8^m$
  - Near the instability strip
- Low amplitude periodic RV variations
  - 87.8, 9.8 days (Hatzes & Cochran 1995)
  - 77.7 days (Butler 1998)
  - 128 days (Lee+ 2012)



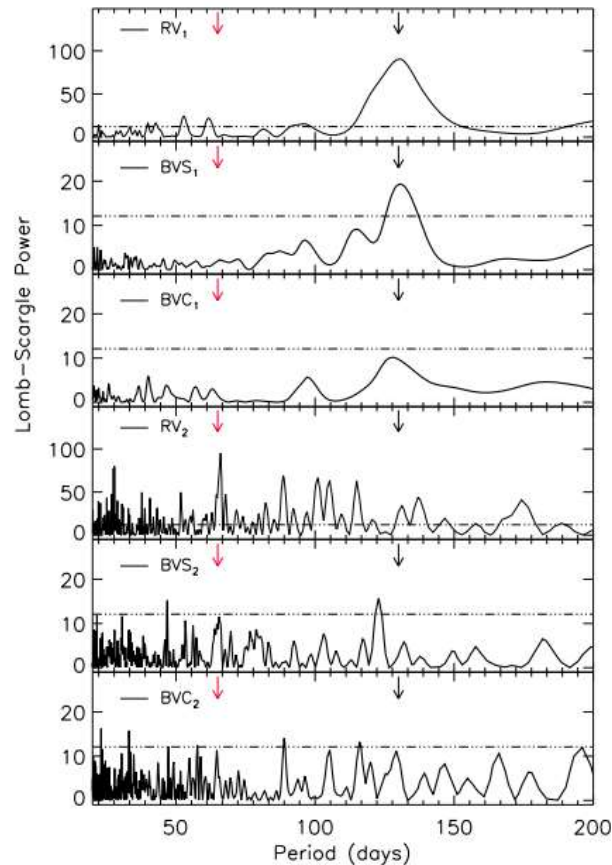
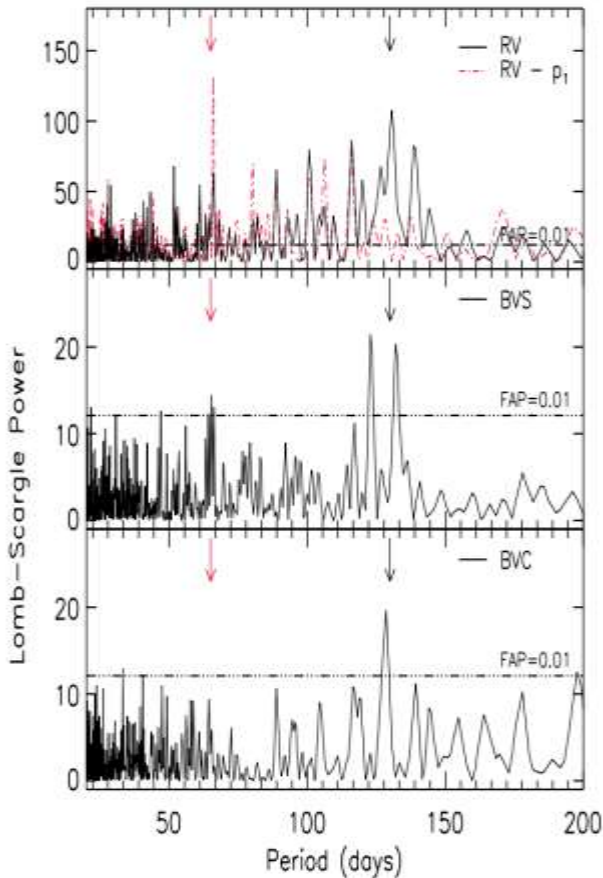
Credit: Martin Gembec

- 2005 ~ 2020, 884 spectra
  - Including 442 spectra from Lee+ (2012)





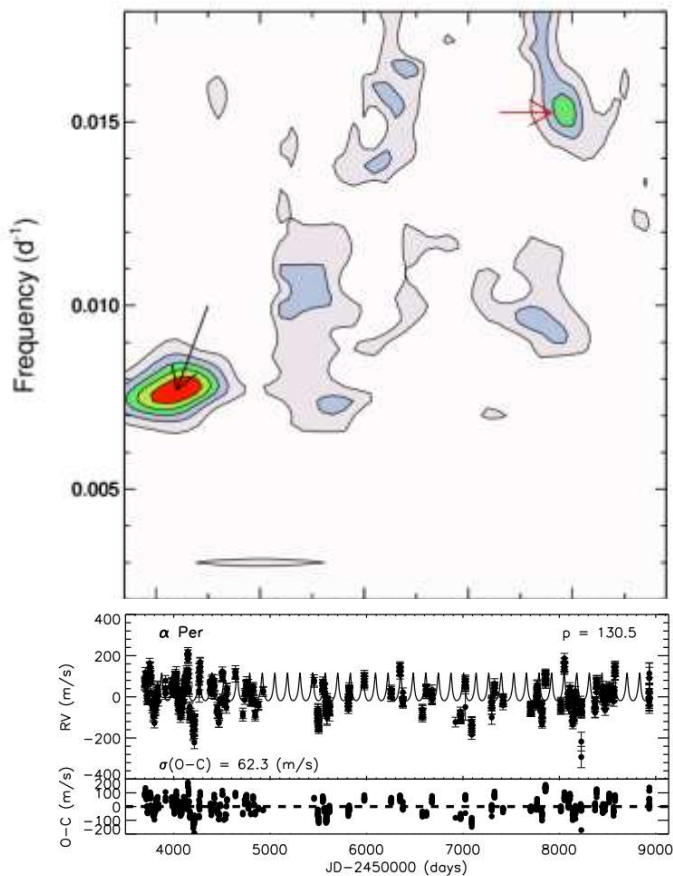
# $\alpha$ Persei – Variations of RVs and Bisectors



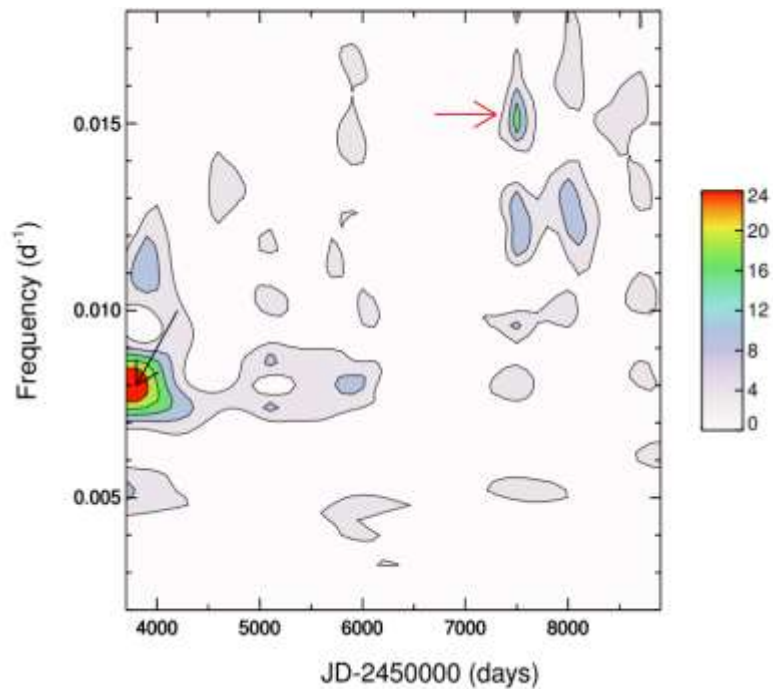
	RVs	BVSs	BVCs
whole	130.5	122, 132	128
Data <sub>1</sub>	130.5	130.5	128
Data <sub>2</sub>	66	122.8	x

- RVs, BVSs, and BVCs have the same primary periods of about 130 days both in whole data and in Data1.
- Primary period has changed in RVs, BVSs, and BVCs.

# Wavelet analysis – Mode switching?



Radial Velocity



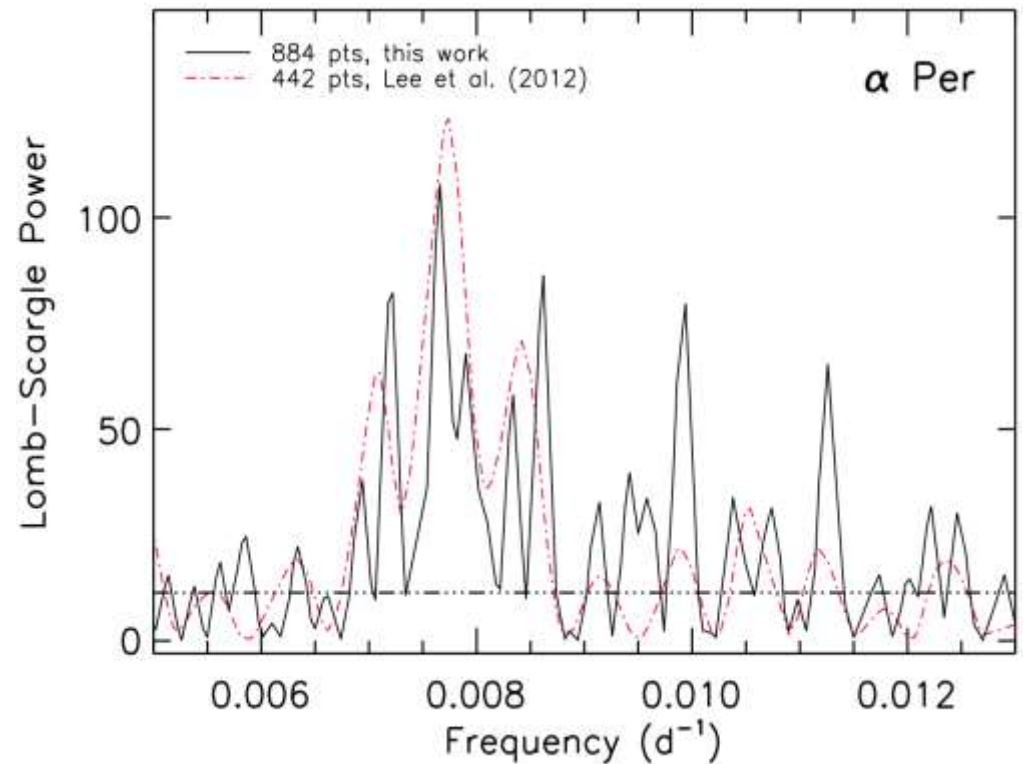
Velocity Bisectors

- Rotational Modulations?

- 130 days
- 66 days: harmonics?
- $P_{\text{rot}}/\sin i = 136.1$  days.  
Almost edge-on? (Lee+ 2012)

- Multiple frequencies

- Hard to explain by rotational modulation of surface features



- Non-radial oscillations
  - 130 or 66 days are too long for fundamental modes
  - Non-radial g-mode with low  $m$  can produce low-amplitude and long period RV variations (Hatzes & Cochran 1999)
  - Multiple periods are expected.
  - Mechanisms of non-radial oscillations in giants are not fully understood.
- Orbiting companions?
  - Variations are seen both in RV and line bisectors variations
  - Unlikely.