

# Exoplanet Surveys with BOES

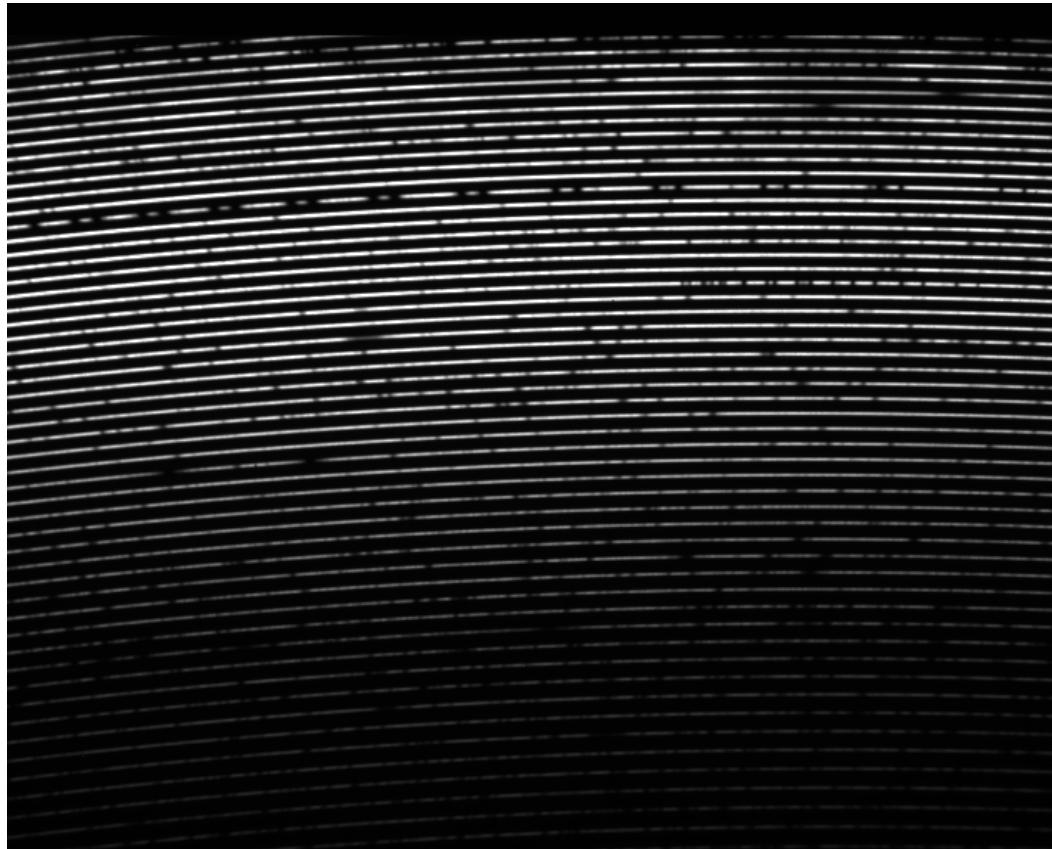
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Kyungpook National University

# 1. Exoplanet search in Korea

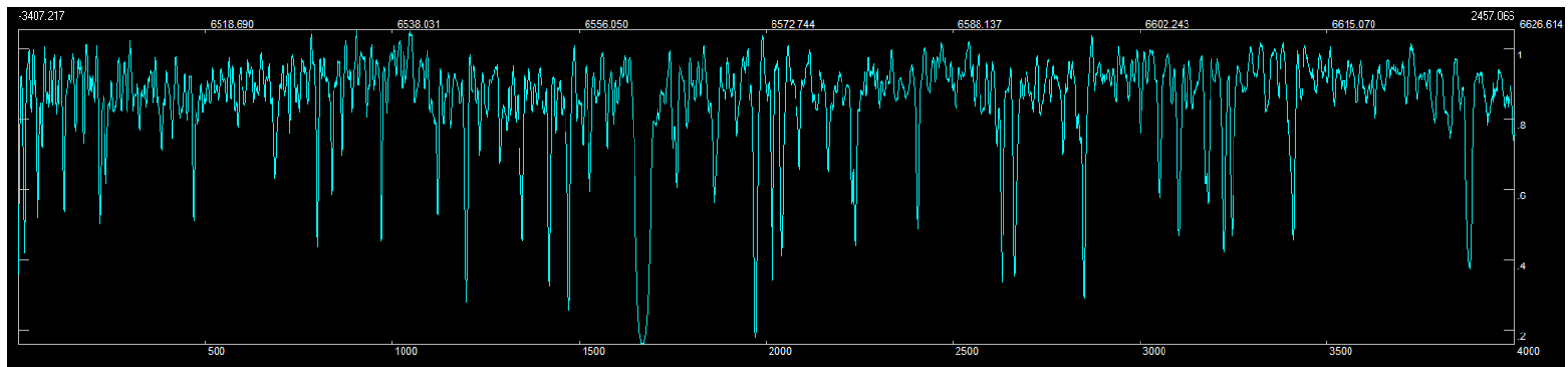
- Photometric methods
  - Eclipsing binary
  - Microlensing
  - Transit method
- Spectroscopic methods
  - Radial velocity measurement
    - Periodic RV variation from orbital motion

## 2. Procedures to find exoplanet

- Raw spectrum



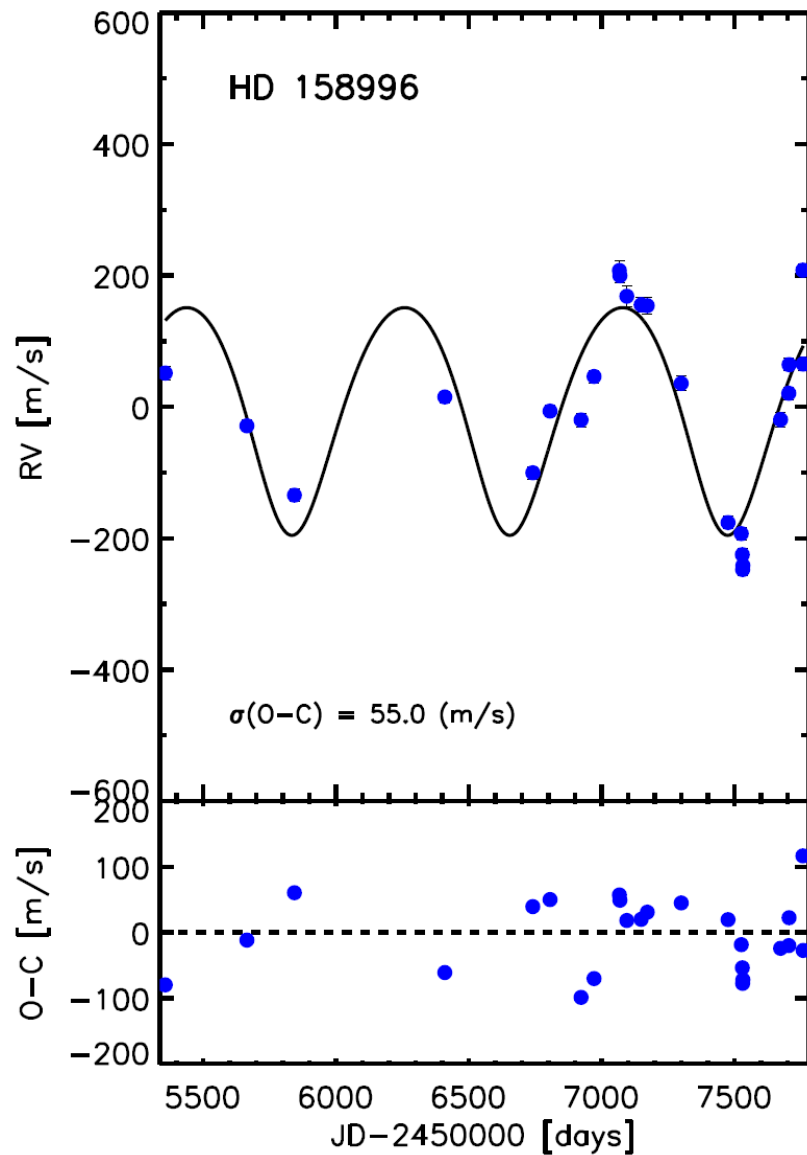
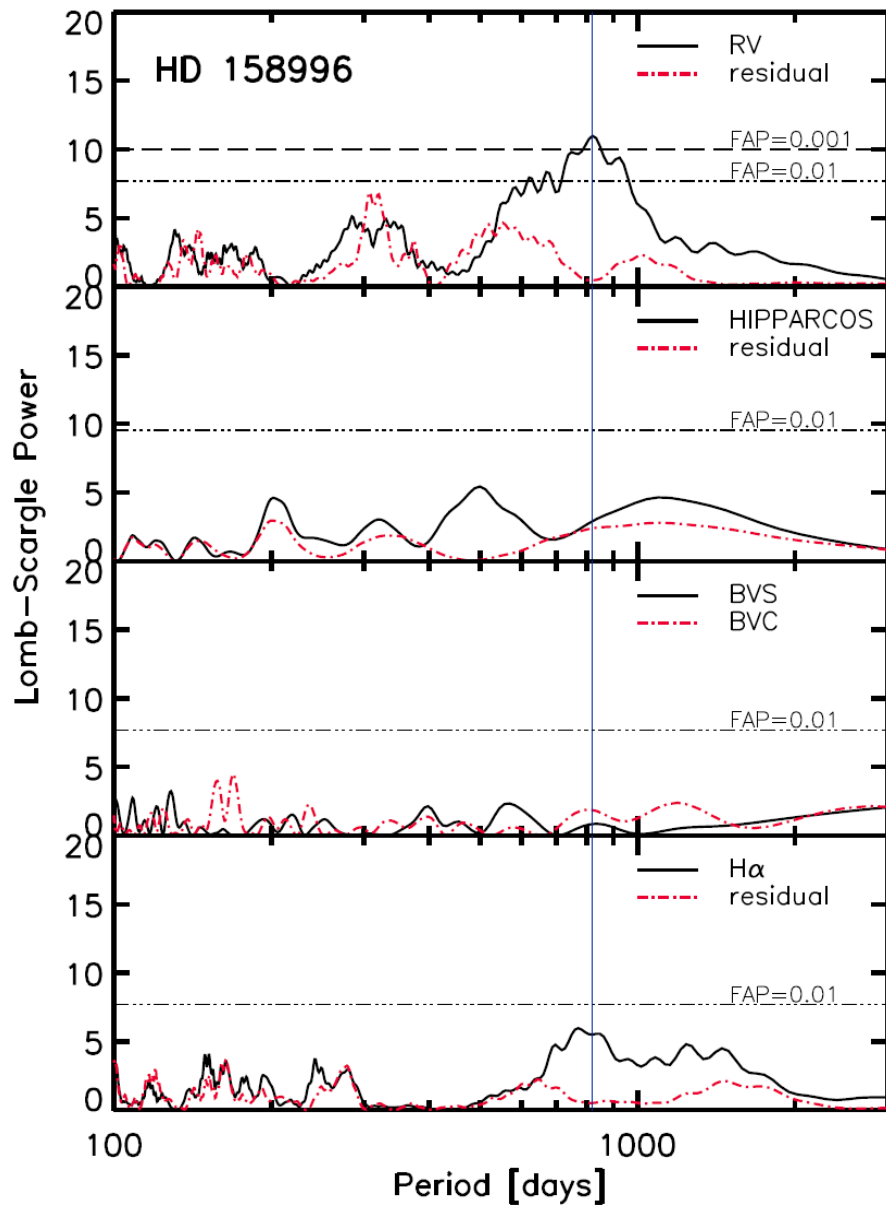
- 1D spectrum



- Stellar parameters

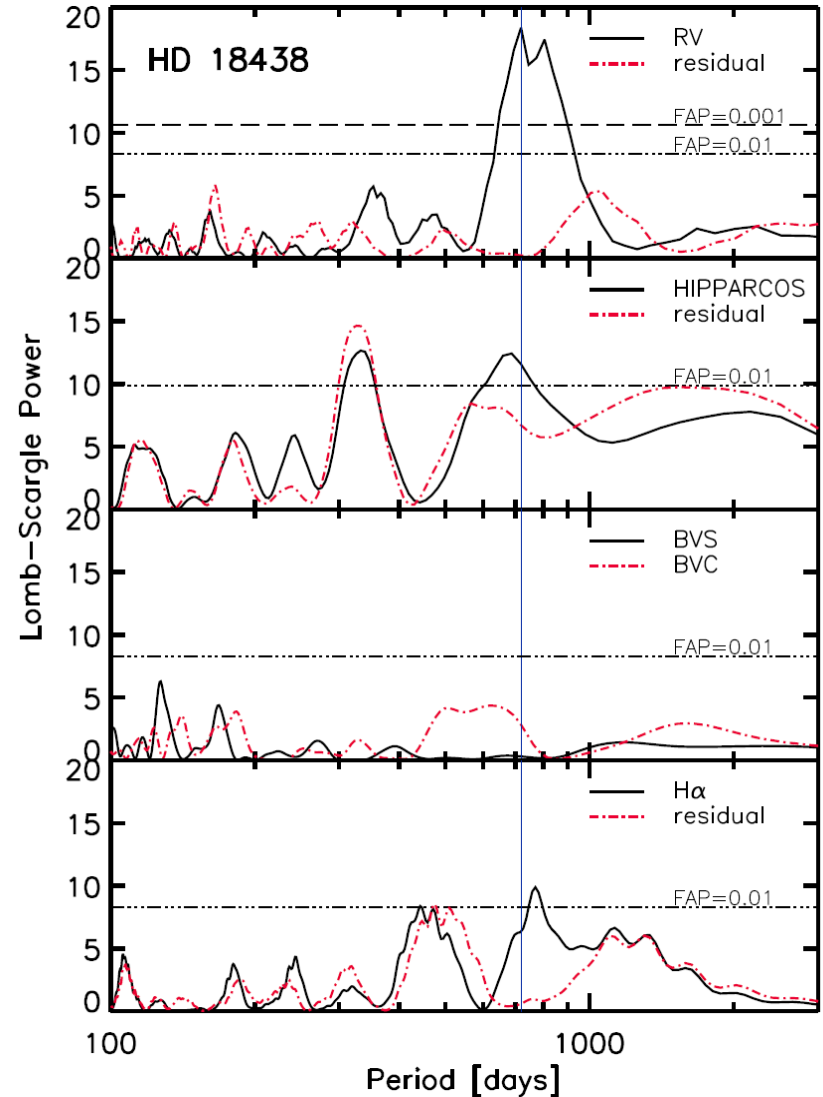
- Line fitting
- Temperature, surface gravity, rotation, metallicity

- RV measurement
  - I<sub>2</sub> absorption cell for wavelength calibration
  - RV determination
    - RVI2CELL (Han et al. 2007)
  - Search for periodicity
    - Lomb-Scargle periodogram
    - Keplerian fitting



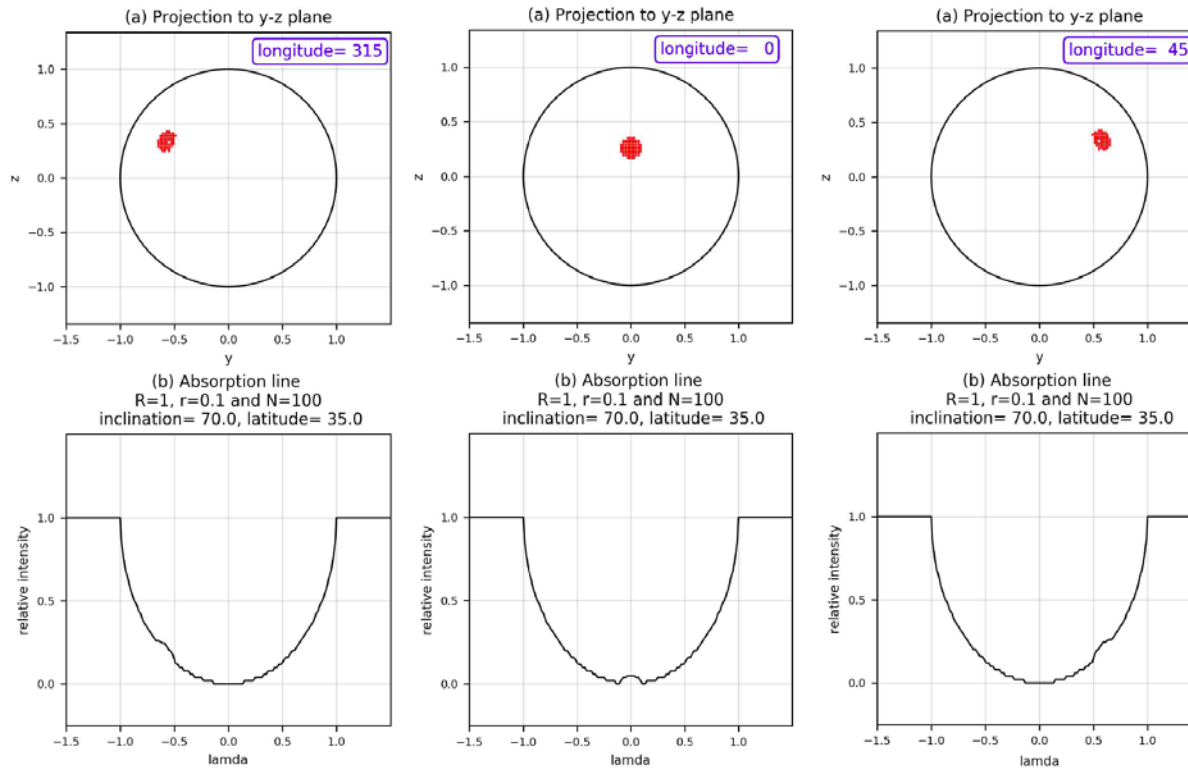
# 3. Pulsations

- Photometric variation
- Long Secondary Periods (LSP) in AGB stars
  - 400 ~ 1500 days
  - $\Delta V \sim 5 \text{ km s}^{-1}$



# 4. Rotation

- Rotating stars with surface features



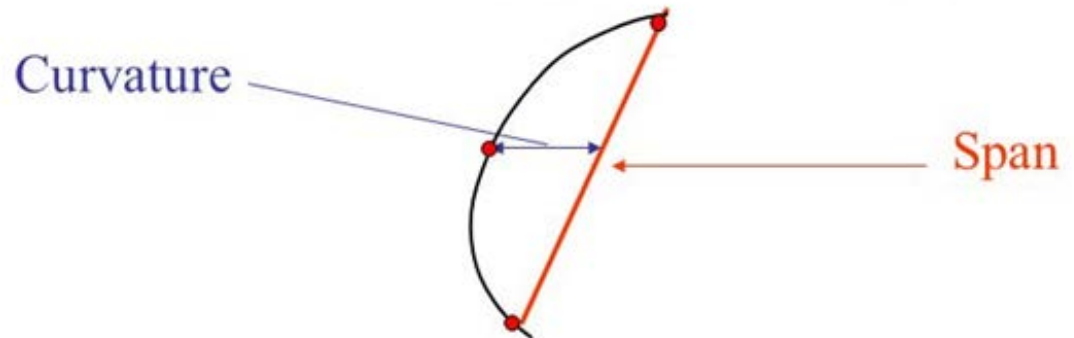
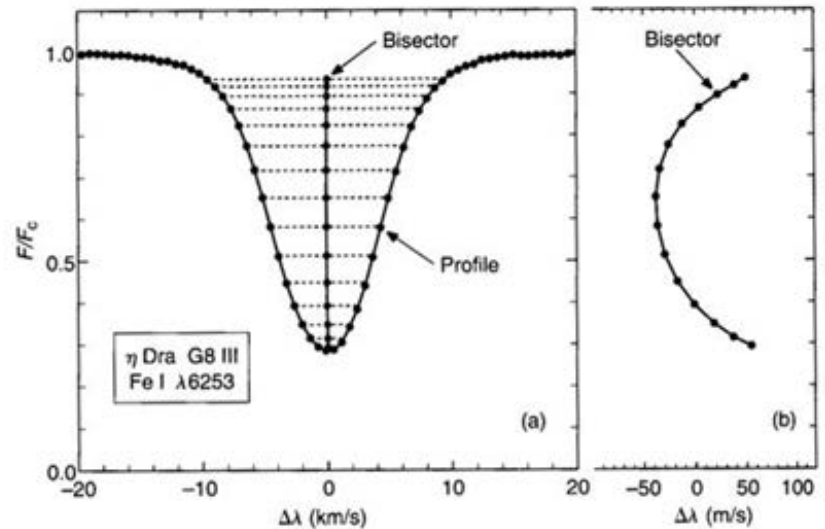
이가인

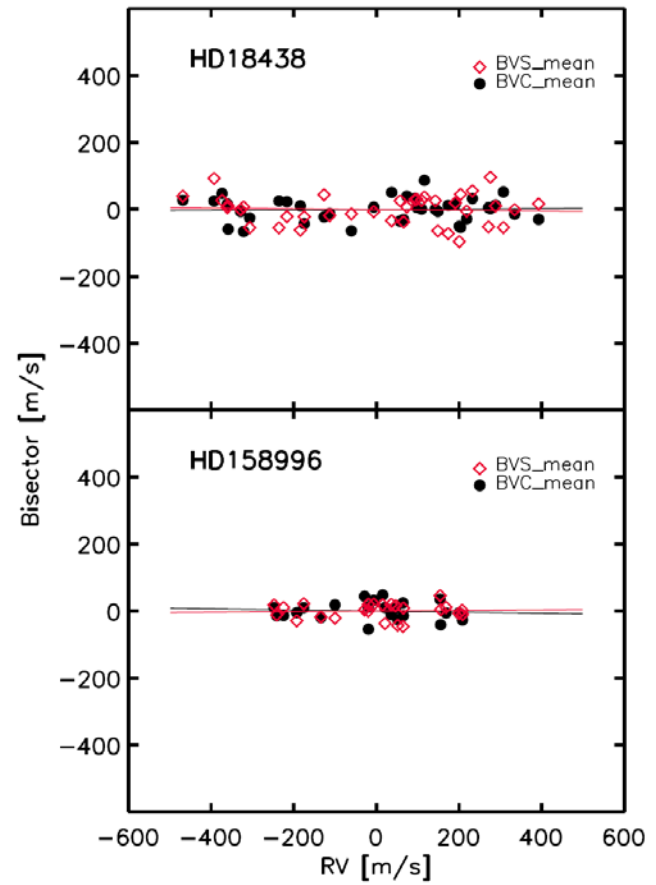
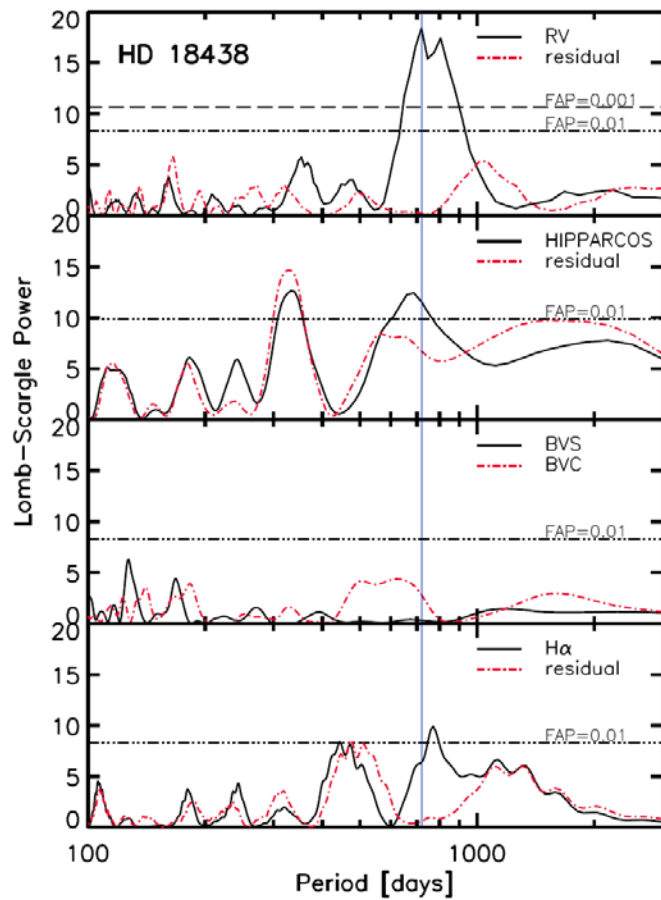


- Observable phenomena

- Line profile variation

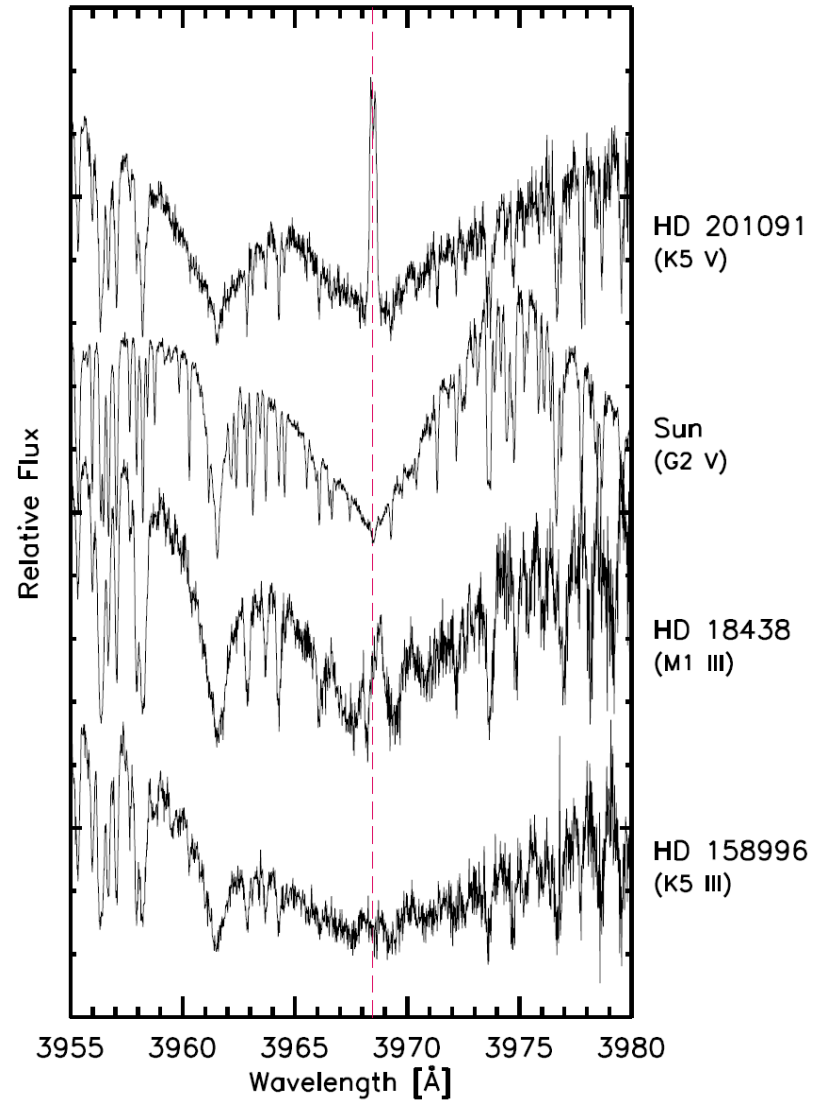
- Bisector Velocity Span (BVS)
- Bisector Velocity Curvature (BVC)
  - Correlation with RV
  - Periodogram





– Chromospheric activity indicator lines

- Ca II H, H alpha
- Line reversal
- EW variation



## 5. BOES

- Bohyunsan Observatory Eschelle 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  $\sim 7 \text{ m s}^{-1}$

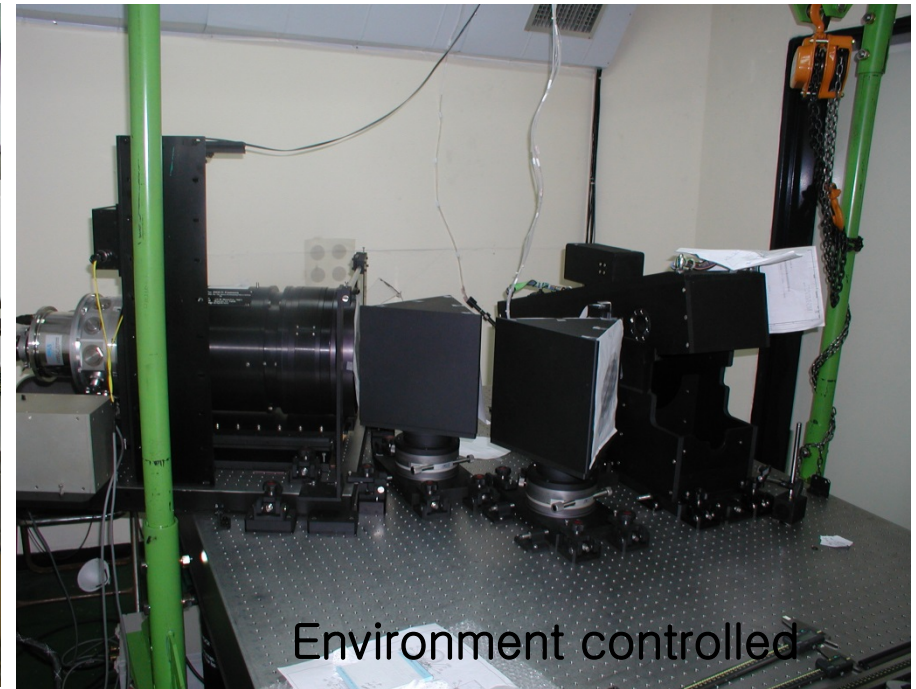
# BOES configuration

한인우/이병철

CIM (Cassegrain Interface Module)



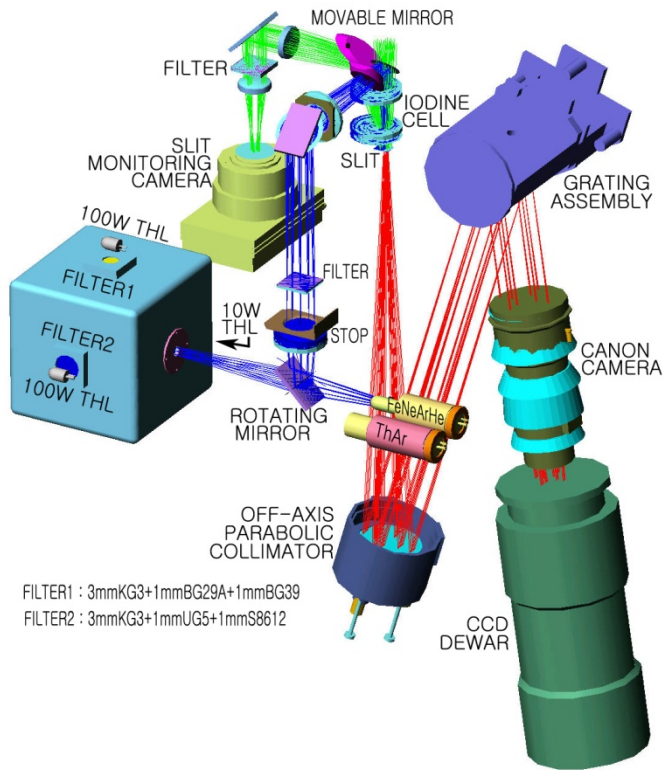
Spectrograph on stable optical table



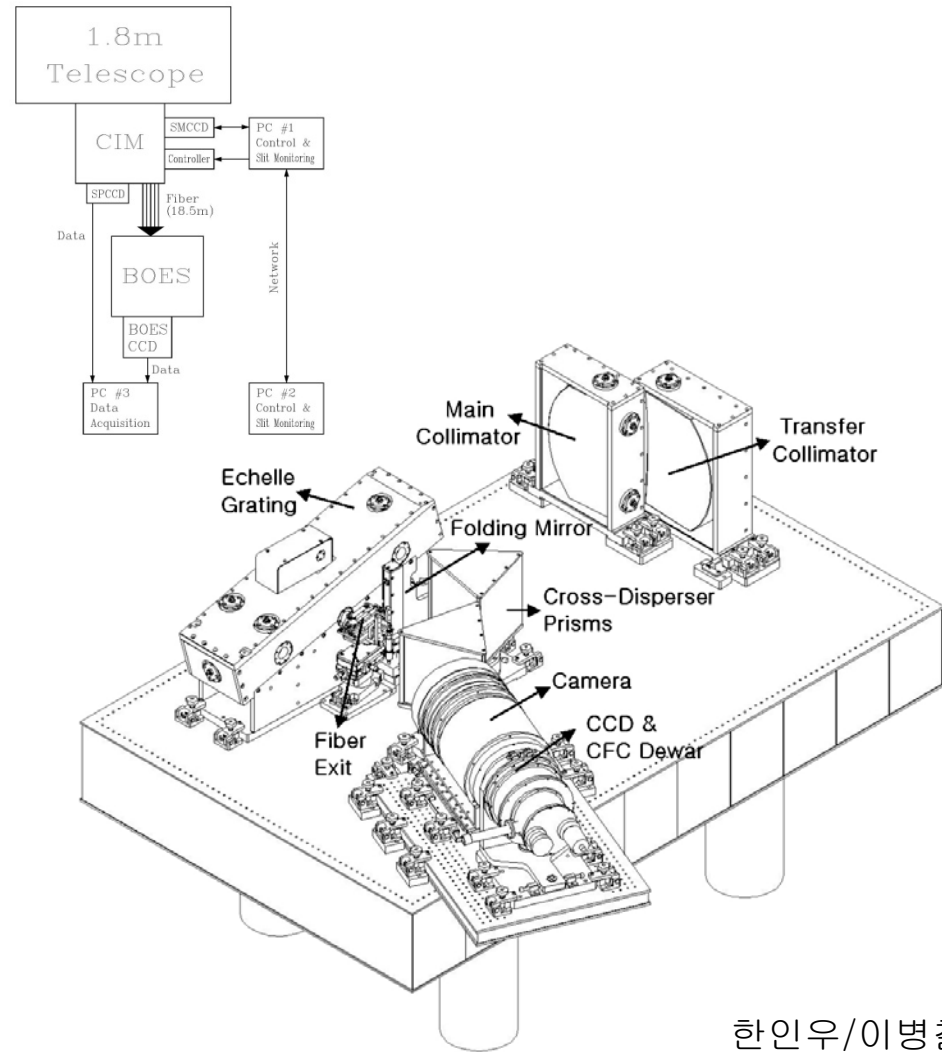
- fiber input
- Slit Monitoring System for A&G
- Calibration Lamp System
- Long Slit Spectrograph

- Fiber output
- collimator
- Echelle grating & cross disperser
- camera & ccd

# BOES



**Slit Monitoring System**  
**Calibration Lamp System**  
**Long Slit Spectrograph**



한인우/이병철

# 6. Exoplanet Surveys with BOES

- Members
  - Byeong-Cheol Lee, Inwoo Han, Kang-Min Kim, Gwanhui Jeong (KASI)
  - MGP, Tae-Yang Bang (KNU)
  - David E. Mkrtychian (Ukraine), Artie P. Hatzes (Germany)
  - Japanese & Chinese collaborators
- Exoplanets around F, G, K, M giants
  - Long period (100 ~ 1000 days) RV variations
- Search for Exoplanets around Northern circumpolar Stars (SENS)
  - No aliasing from seasonal variation

# Exoplanets from BOES

ig	Program	duration	sample	planet	candi	Result (paper)
1	K giant	2003-2017	~50	10	2	8
2	F,M giant	2003-2017	~20		1	2
3	G giant (K-J)	2005-	188	2	~10	2
4	K dwarf	2008-2013	40	2	-	1
5	Binary		9	0	1	0
6	SENS I (K-C)	2010-2017	~220	7	~17	2
7	SENS II (K-C-J)	2017-2020	200	0	0	0
<b>sum</b>			<b>700&lt;</b>	<b>20&lt;</b>	<b>30&lt;</b>	<b>15</b>



# Summary of the characteristics of exoplanets discovered by BOES (1/3)

		host star								planet							
	HD	sp. type	mag	T_eff (K)	[Fe/H]	log g	mass (Sun)	radius (Sun)	lumin	period (days)	K (m/s)	e	mass	a (AU)	rms (m/s)	discovery	comment
1	11755	G5	6.87	4312.5 ±5.0	-0.74 ±0.02	1.67 ±0.03	0.9 ±0.1	27.3 ±1.0	145.7 2	433.7 ±3.2	191.3 ±10.2	0.19 ±0.10	6.5 ±1.0	1.08 ±0.04	27.7	2015	
2	12529 <u>α Ari</u>	K2 III	2.01	4553 ±15	-0.09 ±0.03	2.33 ±0.06	1.5 ±0.2	13.9 ±0.3	-	380.8 ±0.3	41.1 ±0.8	0.25 ±0.03	1.8 ±0.2	1.2	17.8	2011	real planet?
3	12648	G5	6.98	4835.8 ±7.5	-0.57 ±0.02	2.18 ±0.03	1.2 ±0.1	9.2 ±0.6	45.01	133.6 ±0.5	102.0 ± 8.4	0.04 ±0.16	2.9 ±0.4	0.54 ±0.02	29.8	2015	
4	19615	K0	6.57							402.1 ±3.8	300 ±30	0.4 ±0.2			75	candi	sens5
5	20902 <u>α Per</u>	F5 Ib	1.82	6240 ±20	-0.28 ±0.06	0.58 ±0.04	7.3 ±0.3	60.7	5500	128.2 ±0.1	70.8 ±1.5	0.10 ±0.04	6.6 ±0.2	0.97	44.8	2012 candi	planet? pulsation? rotation?
6	21552 <u>σ Per</u>	K3 III	4.36	4201 ±22	-0.21 ±0.06	1.77 ±0.09	2.25 ±0.5	28	316.2	579.8 ±2.4	96.0 ±6.5	0.3 ±0.1	6.5 ±1.0	1.8 ±0.1	33.7	2014	
7	24064	K0	6.75	4052.5 ±22.5	-0.49 ±0.06	1.44 ±0.11	1.0 ±0.1	38.0 ±2.9	352.9 0	535.6 ±3.0	251.0 ±9.3	0.35 ±0.08	9.4 ±1.3	1.29 ±0.05	34.5	2015	
8	29139 Aldebaran	K5III	0.85	4055 ±70	-0.27 ±0.05	1.2 ±0.1	1.13 ±0.11	45.1 ±0.1	-	628.96 ±0.90	142.1 ±7.2	0.10 ±0.05	6.47 ±0.53	6.47 ±0.53	-	2015	CFHT+D AO+McD +TLS +BOAO
9	40956	K0	6.58	4869 ±28	0.14 ±0.05	3.02 ±0.09	2.00 ±0.08	8.56 ±0.33	46.17	578.6 3.3	68 ±2	0.24 ±0.05	2.7 ±0.6	1.4 ±0.1	~20	2017	BOAO +OAO
10	44385	K0 III	6.77	4440 ±28	0.10 ±0.07	2.00 ±0.12	2.0 ±0.3	20.3 ±4.9	233.2	473.9 ±5.2	106 ±11	0.20 ±0.21	6.3 ±1.2	1.5 ±0.1	42.8	candi	sens4
11	52030	M1 III	6.49	3970 ±30	-0.54 ±0.08	1.3 ±0.1	1.09 ±0.16	53.0 ±6.1	867	484.3 ±4.2	329.0 ±21.8	0.14 ±0.14	13.3 ±2.3	1.2 ±0.1	82.1	2017	largest, AGB stage
12	66141	K2 III	4.39	4323 ±15	-0.323 ±0.034	1.92 ±0.07	1.1 ±0.1	21.4 ±0.6	174	480.5 ±0.5	146.2 ±2.7	0.07 ±0.03	6.0 ±0.3	1.2 ±0.1	38.8	2012	

# Summary of the characteristics of exoplanets discovered by BOES (2/3)

	host star									planet							
	HD	sp. type	mag	T <sub>eff</sub> (K)	[Fe/H]	log g	mass (Sun)	radius (Sun)	lumin	period (days)	K (m/s)	e	mass	a (AU)	rms (m/s)	discovery	comment
13	69267 <a href="#">β Cnc</a>	K4 III	3.52	4092.1 ±17.5	-0.29 ±0.06	1.4 ±0.1	1.7± 0.1	47.2 ±1.3	785.7	605.2 ±4.0	133.0 ±8.8	0.08 ±0.02	7.8 ±0.8	1.7 ±0.1	47.2	2014	
14	85503 <a href="#">α Leo</a>	K2 III	3.88	4538.2 ±27.5	0.36± 0.05	2.4± 0.1	1.5 ±0.1	11.4± 0.2	62.62	357.8 ±1.2	52.0 ±5.4	0.09 ±0.06	2.4 ±0.4	1.1 ±0.1	14.2	2014	
15	89484 <a href="#">γ1 Leo</a>	K0 III	2.01	4330 ± 15	-0.51 ±0.05	1.59	1.23 ±0.21	31.88 ±1.61	-	428.5 ±1.25	208.3 ±4.3	0.144 ±0.04 6	8.78 ±1.0	1.19 ±0.02	43	2010	
16	97619	K0 III	7.04	4355 ±20	-0.07 ±0.07	2.33 ±0.09	1.2 ±0.1	15.9 ±1.4	122.8	667.7 ±26.7	71±13	0.28 ±0.30	3.3 ±1.4	1.6 ±0.1	26.8	<a href="#">candi</a>	sens4
17	100655	G9 III	6.45	4861 ±110	0.15 ±0.12	2.89 ±0.10	2.4 ±0.3	2.4 ±0.3		157.57 ±0.65	35.2 ±2.3	0.085 ±0.05 4	1.7 ±+0.1	0.76 ±+0.3	11.2	2012	<a href="#">BOAO</a> <a href="#">+OAO</a>
18	106574	K2 III	5.88	4501 ±33	-0.43 ±0.04	2.18 ±0.18	3.7 ±0.5	50.0 ±7.0	152.2	1071.1 ±15.1	149±8	0.03 ±0.11	17.9 ±1.0	3.2 ±0.1	41.2	<a href="#">candi</a>	sens4
19	111591	K0 III	6.59	4884 ±30	0.07 ±0.04	3.10 ±0.10	1.94 ±0.07	8.03 ±0.49	38.07	1056.4 ±14.3	59±3	0.26 ±0.10	4.4 ±0.4	2.5 ±0.1	~15	2017	<a href="#">BOAO</a> <a href="#">+OAO</a>
20	113996	K5 III	4.92	4181 40	0.13 0.08	1.86 0.16	1.49 0.18	25.11 1.20	291.0 0	610.2 ±3.8	120±9	0.28 ±0.12	6.3 ±1.0	1.6 ±0.1	39.3	2017	
21	118904	K2 III	5.67	4469 ±23	-0.11 ±0.09	±2.13 0.10	1.6 ±0.2	17.2 ±0.7	152.4	675.8 ±22.9	61±9	0.31 ±0.33	3.3 ±1.4	1.8 ±0.1	34.5	<a href="#">candi</a>	sens4
22	131873 <a href="#">β UMi</a>	K4 IIIvar	2.08	4126.0 ±25.0	-0.27 ±0.07	1.5 ±0.1	1.4 ±0.2	38.3 ±1.1	537.0 7	522.3 ± 2.7	126.1 ±8.1	0.19 ±0.02	6.1 ±1.0	1.4 ±0.1	40.5	2014	
23	133086 <a href="#">8 UMi</a>	K0	6.83	4847.4 ±7.5	-0.03 ±0.02	2.57 ±0.03	1.8 ±0.1	9.9 ±0.4	55.94	93.4 ±4.5	46.1 ±4.0	0.06 ±0.18	1.5 ±0.2	0.49 ±0.03	17.2	2015	
24	142795	K2	6.85							781 ±6	192 ±16	0.26 ±0.15			44	<a href="#">candi</a>	sens5
25	143107 <a href="#">ε CrB</a>	K2 III	4.14	4406 ±15	-0.094 ±0.00 1	1.94 ±0.08	1.7 ±0.1	21	151	417.9 ±0.5	129.4 ±2.0	0.11 ±0.03	6.7 ±0.3	1.3	25.0	2012	
26	150010	K2 III	6.27							524.6 ±6.9	59 ±6	0.2 ±0.2			27	<a href="#">candi</a>	sens5
27	158996	K5 III	5.8	4069 30	-0.2 ±0.1	1.4 ±0.1	1.8 ±0.3	50.3 ±4.3	1034. 7	820.2 ±14.0	207 ±14	0.13 ±0.05	0.13 ±0.05	2.1 ±0.2	57.8	2017	<b>brightest</b>
28	164058 <a href="#">γ Dra</a>	K III <sup>5</sup>	2.24														no planet by Artie

# Summary of the characteristics of exoplanets discovered by BOES (3/3)

		host star								planet							
	HD	sp. type	mag	T_eff (K)	[Fe/H]	log g	mass (Sun)	radius (Sun)	lumin	period (days)	K (m/s)	e	mass	a (AU)	rms (m/s)	discovery	comment
29	164428	K5 III	6.39	4119 ±40	-0.07 ±0.10	1.62 ±0.17	1.5 ±0.2	33.9 ±2.9	122.8	594.6 ±9.7	108 ±14	0.23 ±0.24	5.6 ±1.1	1.6 ±0.1	51.8	candi	sens4
30	174205	K2	6.28							612 ±13	66 ±9	0.2 ±0.3			38	candi	sens5
31	183030	M1 III	6.31							459 ±22	338 ±48	0.4 ±0.2			107	candi	sens5
32	186063	K0	6.97							301 ±3	116 ±32	0.4 ±0.4			46	candi	sens5
33	202432	K2 III	7.05	4549 ±30	0.16 ±0.10	2.42 ±0.12	1.2 ±0.2	11.0 ±0.4	63.9	422.4 ±5.0	46±4	0.21 ±0.19	1.9 ±0.4	1.2 ±0.1	13.9	candi	sens4
34	204149	G5	6.9							±35 0.1	71 ±10	0.1 ±0.1			35	candi	sens5
35	208527	M1 III	6.4	4035 ±65	-0.09 ±0.16	1.6 ±0.3	1.6 ±0.4	51.1 ±8.3	-	875.5 ±5.8	155.4 ±3.2	0.08 ±0.04	9.9 ±1.7	2.1 ±0.2	39.3	2013	First planet around M-giant
36	208742	M0.5 III	6.51	3940 ±50	-0.47 ±0.20	1.1 ±0.3	1.18 ±0.22	57.2 ±7.1	980	602.8 ±4.9	303.0 ±16.6	0.06 ±0.13	14.0 ±2.0	1.5 ±0.2	55.4	2017	largest, AGB stage
37	220074	M2 III	6.4	3935 ±110	-0.25 ±0.25	1.3 ±0.5	1.2 ±0.3	49.7 ±9.5	-	672.1 ±3.7	230.8 ±5.0	0.14 ±0.05	11.1 ±1.8	1.6 ±0.1	57.4	2013	First planet around M-giant

## 7. Exoplanets around Evolved Giant Stars

- Do evolved giant stars have different probability to host exoplanets?
- Do evolved giant stars with exoplanets have different metallicity?
  - Absorption of exoplanets by the host star?

- Largest stars with exoplanets

