Dynamo Sensitivity in Solar Analogs with 50 Years of Ca II H & K Activity

Ricky Egeland
High Altitude Observatory/Montana State University

collaborators:
Willie Soon – Harvard CfA
Jeffrey C. Hall – Lowell Observatory
Alexei Pevtsov – National Solar Observatory
Gregory W. Henry – Tennessee State University

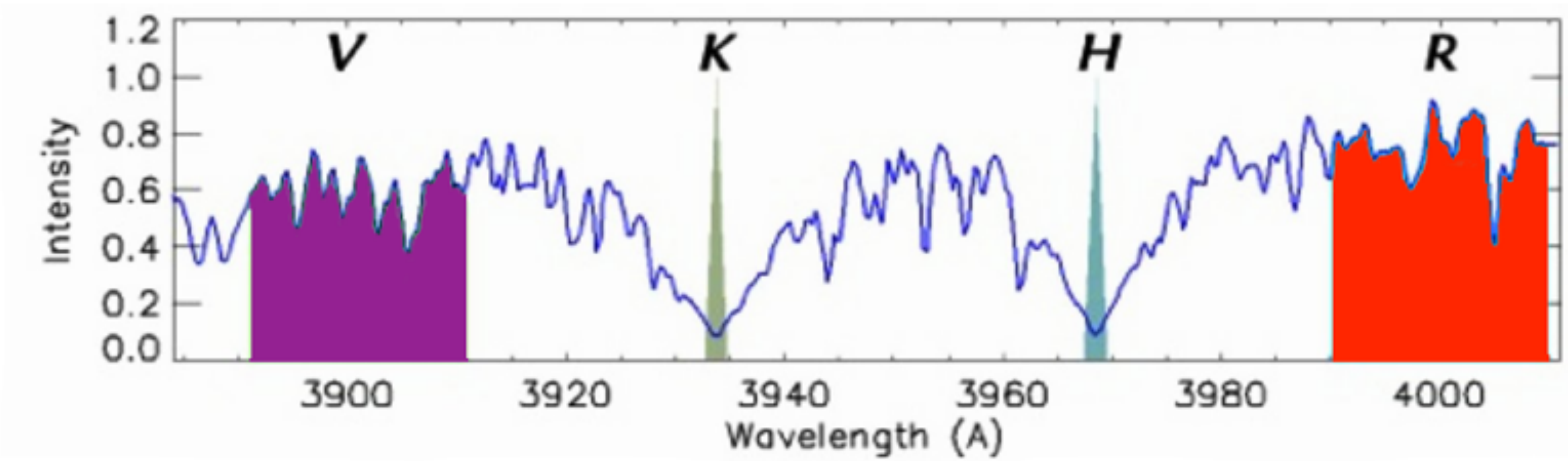
advisors
Phil Judge – High Altitude Observatory
Piet Martens – Georgia State University

The Stellar Dynamo:

Fundamental Properties $\overset{?}{\Rightarrow}$ Long-term Variability

Effective temperature, T_{eff}	median
Radius, R	amplitude
Luminosity, L	flat, cycling (P_{cyc}), erratic
Metalicity, [Fe/H]	
Rotation Period, P_{rot}	

The S-index of Activity



$$S = \alpha \frac{\mathcal{F}_H + \mathcal{F}_K}{\mathcal{F}_V + \mathcal{F}_R}$$

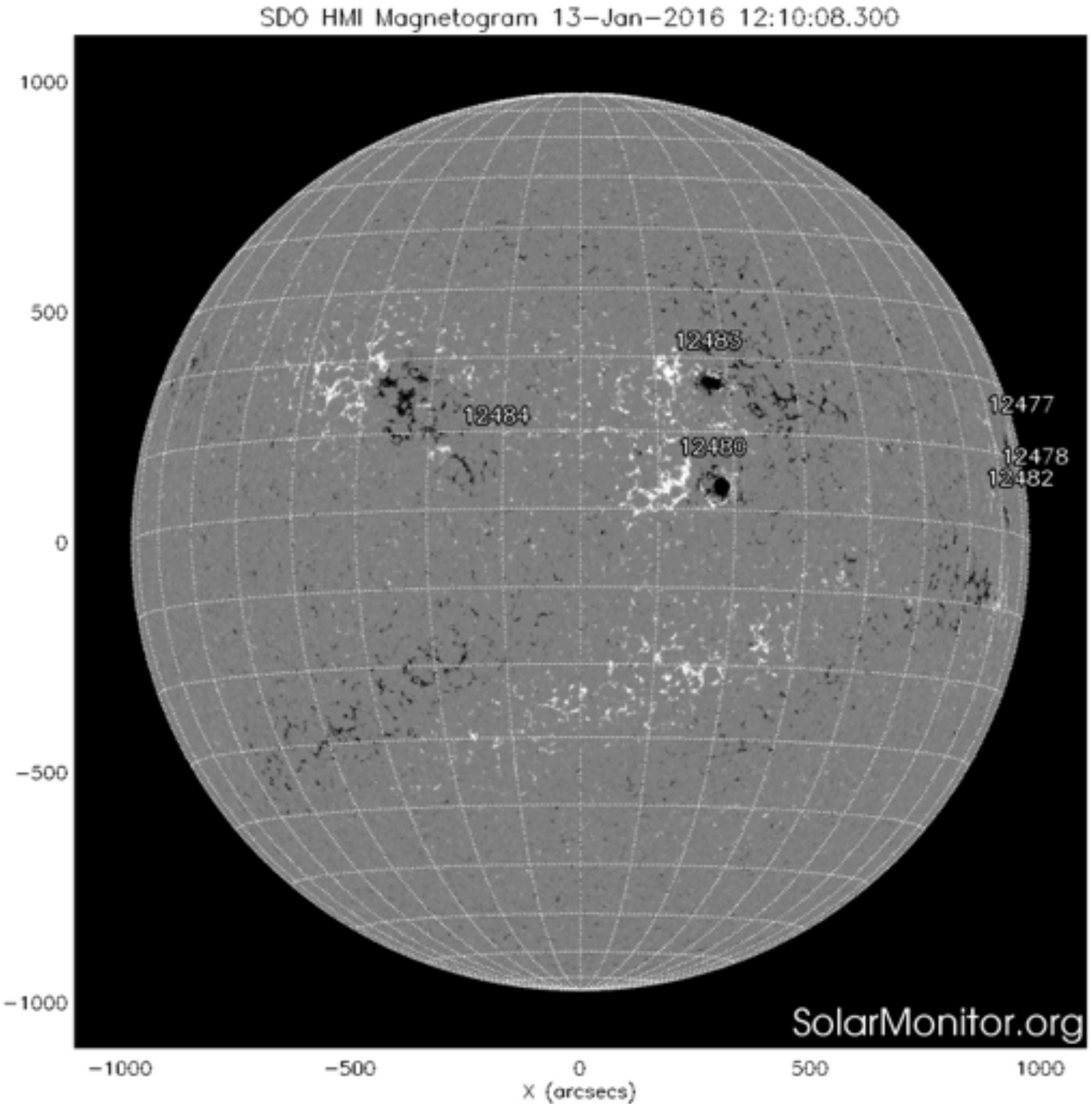
Due to non-thermal chromospheric heating, proportional to surface fields

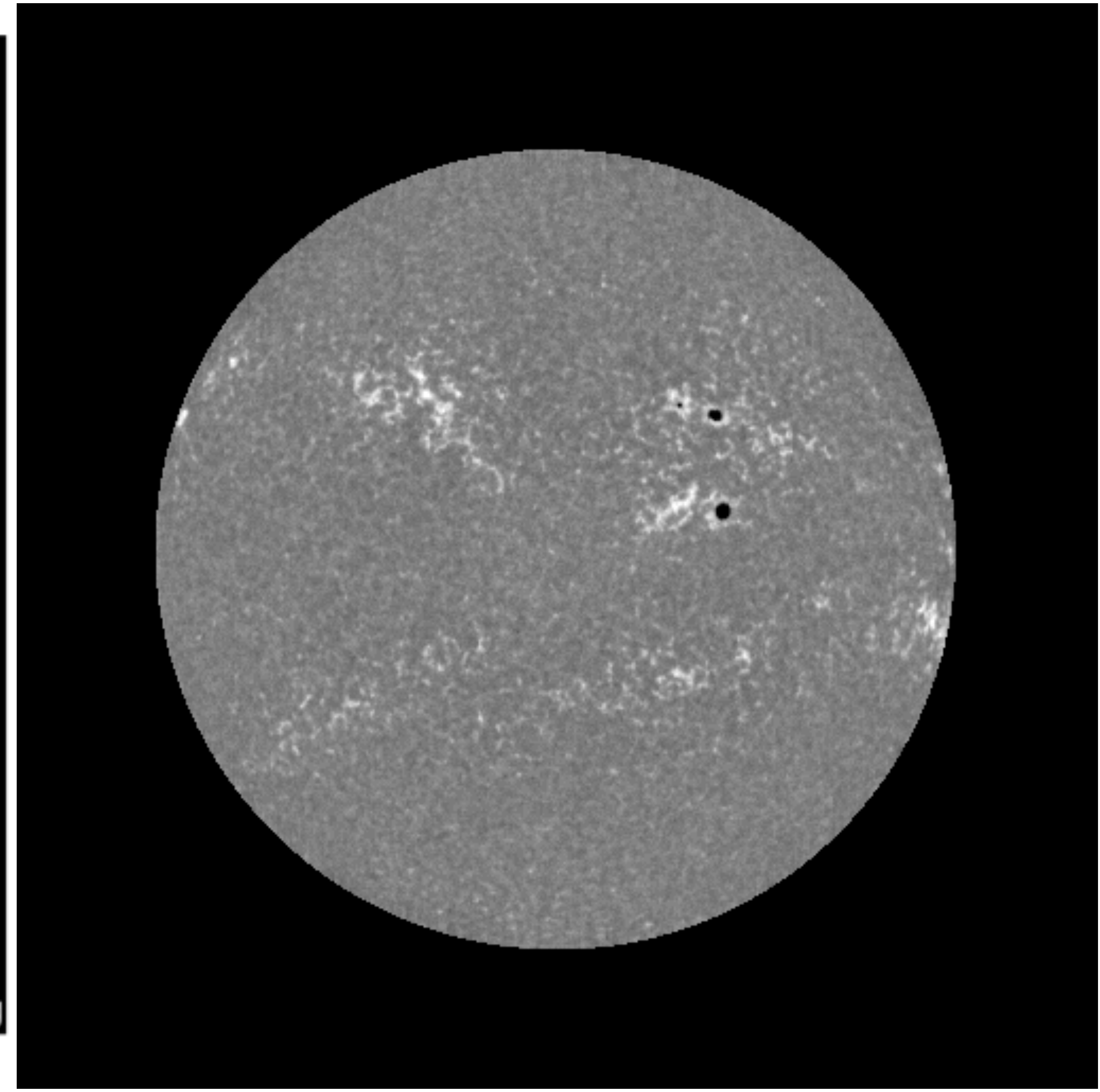
Calibration Factor (2.3)

Reference Bandpass

Vaughan, Preston, Wilson 1978

The Sun in Ca II

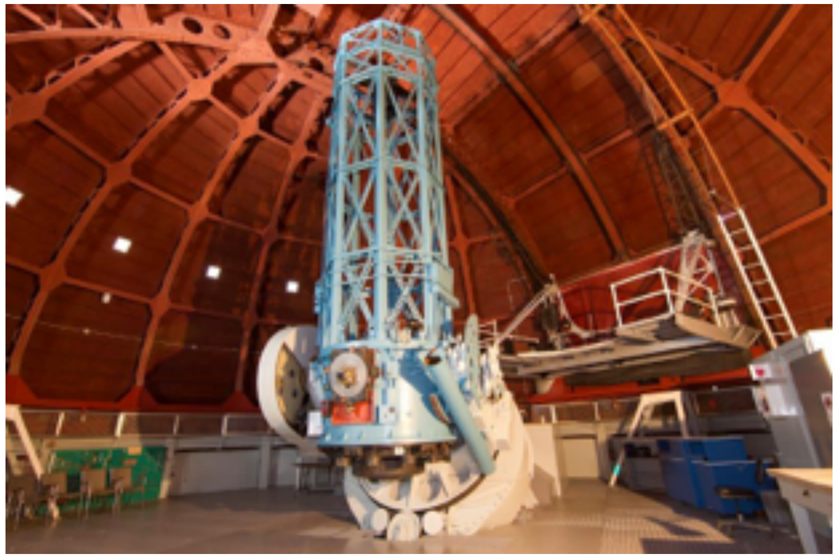




SDO/HMI Magnetogram

San Fernando Observatory
Ca II K-line Intensity
3934 Å, 10 Å wide

The Observatories



Mt. Wilson Observatory

HK project

100-inch: 1966-1977

60-inch: 1977-2003

O. WIlson

S. Baliunas

Lowell Observatory

Solar-Stellar Spectrograph

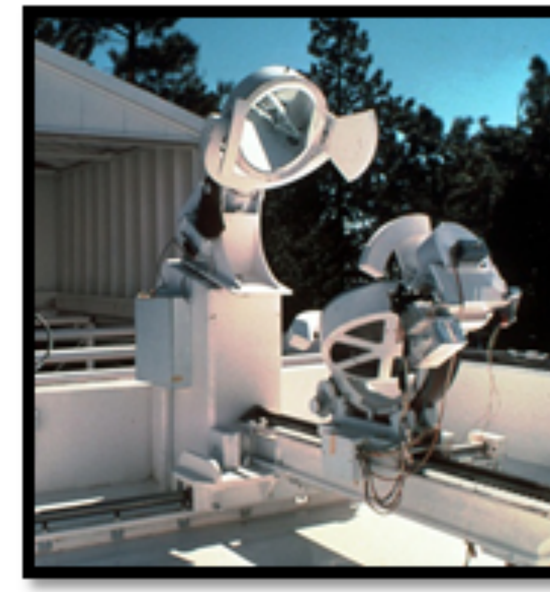
1.1 m

CCD1: 1994–2008

CCD2: 2008–present

J. Hall

R. L. Gilliland
R. Fisher
D. Mihalas
(HAO, ~1988)



Sacramento Peak

NSO/AFRL K-line Program

50 μm eff. aperture

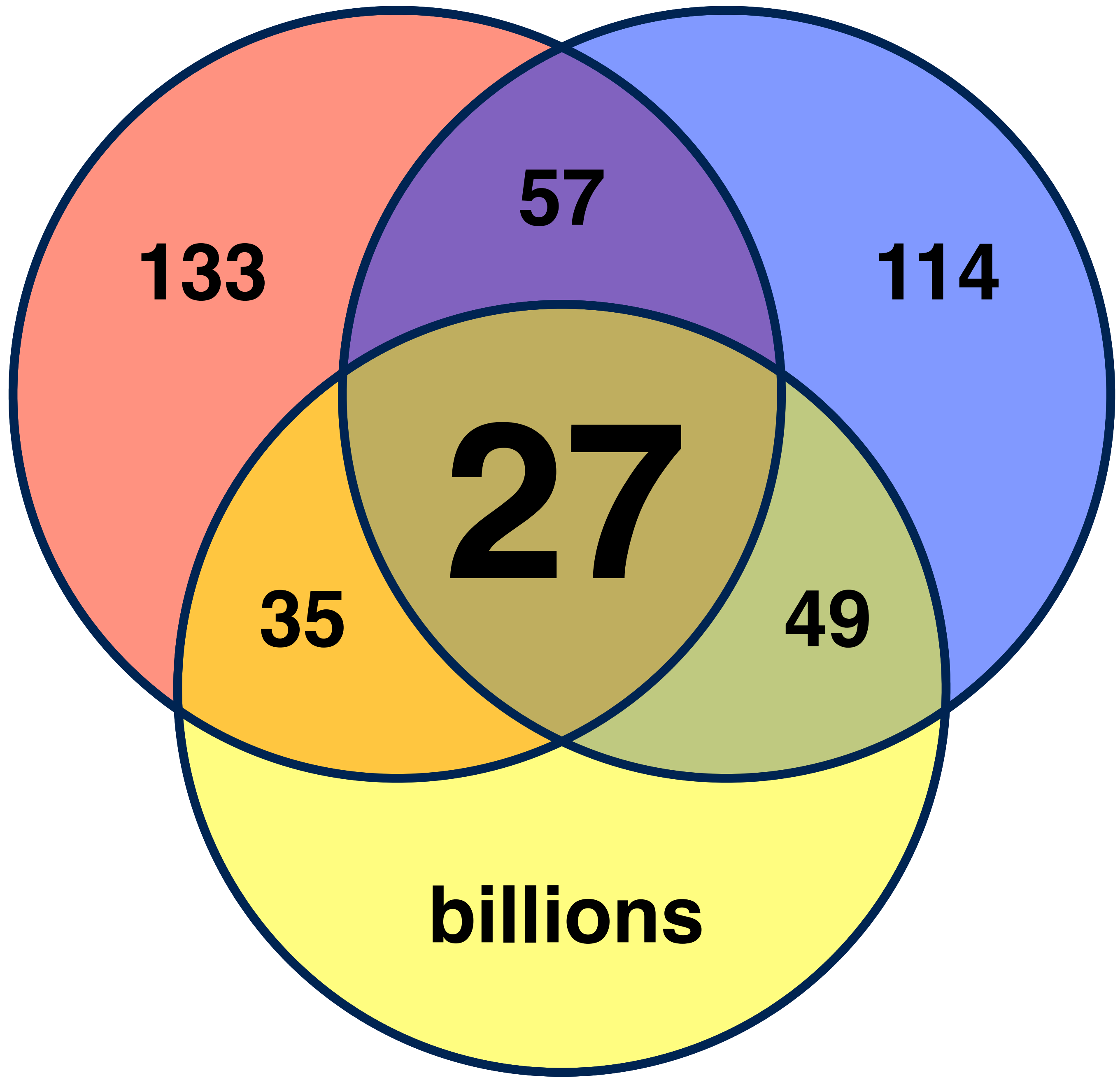
1976–2016

S. L. Keil
T. W. Henry
W. Livingston

Stellar Sample

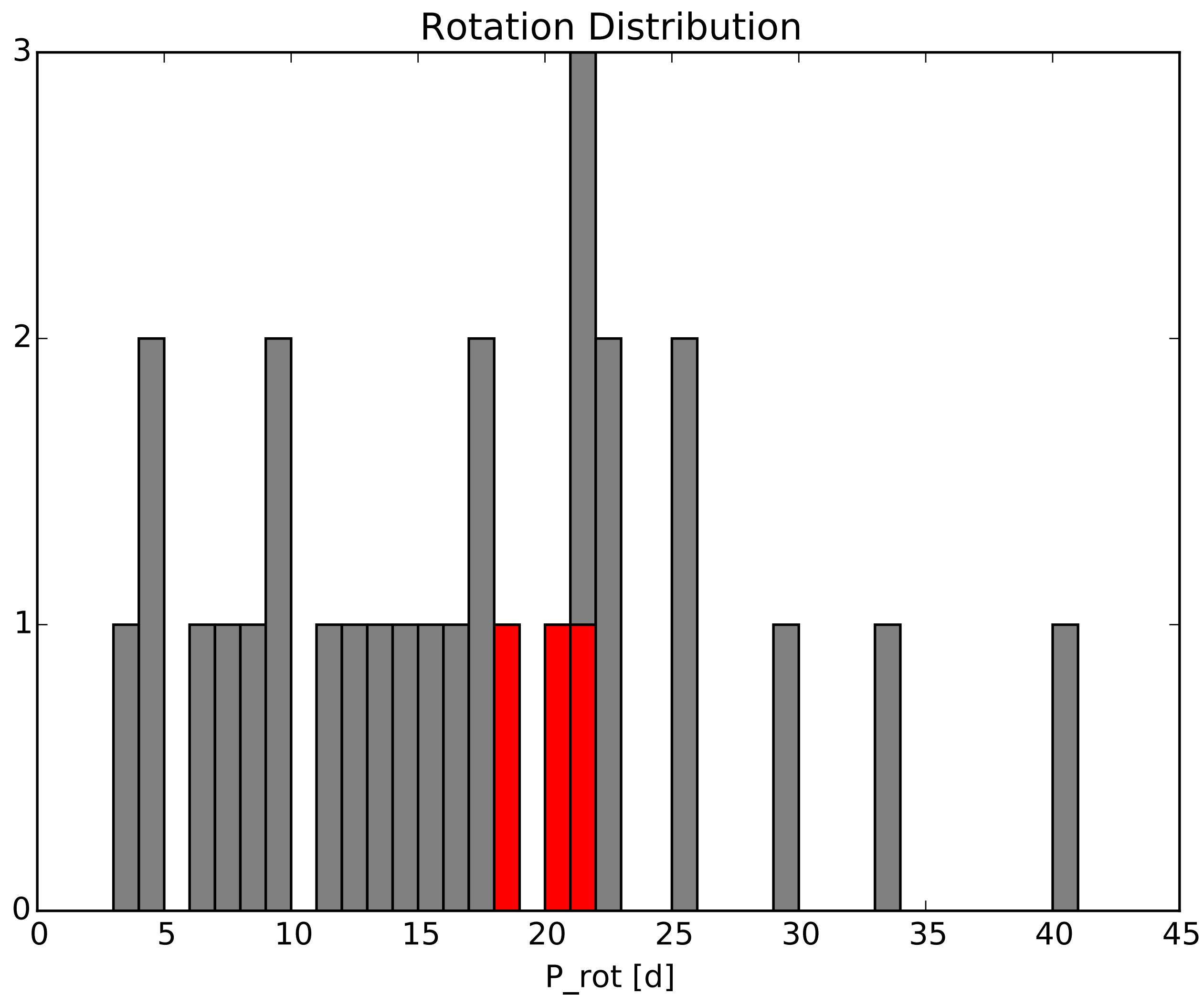
Mount Wilson
HK Project
(1966-2003)

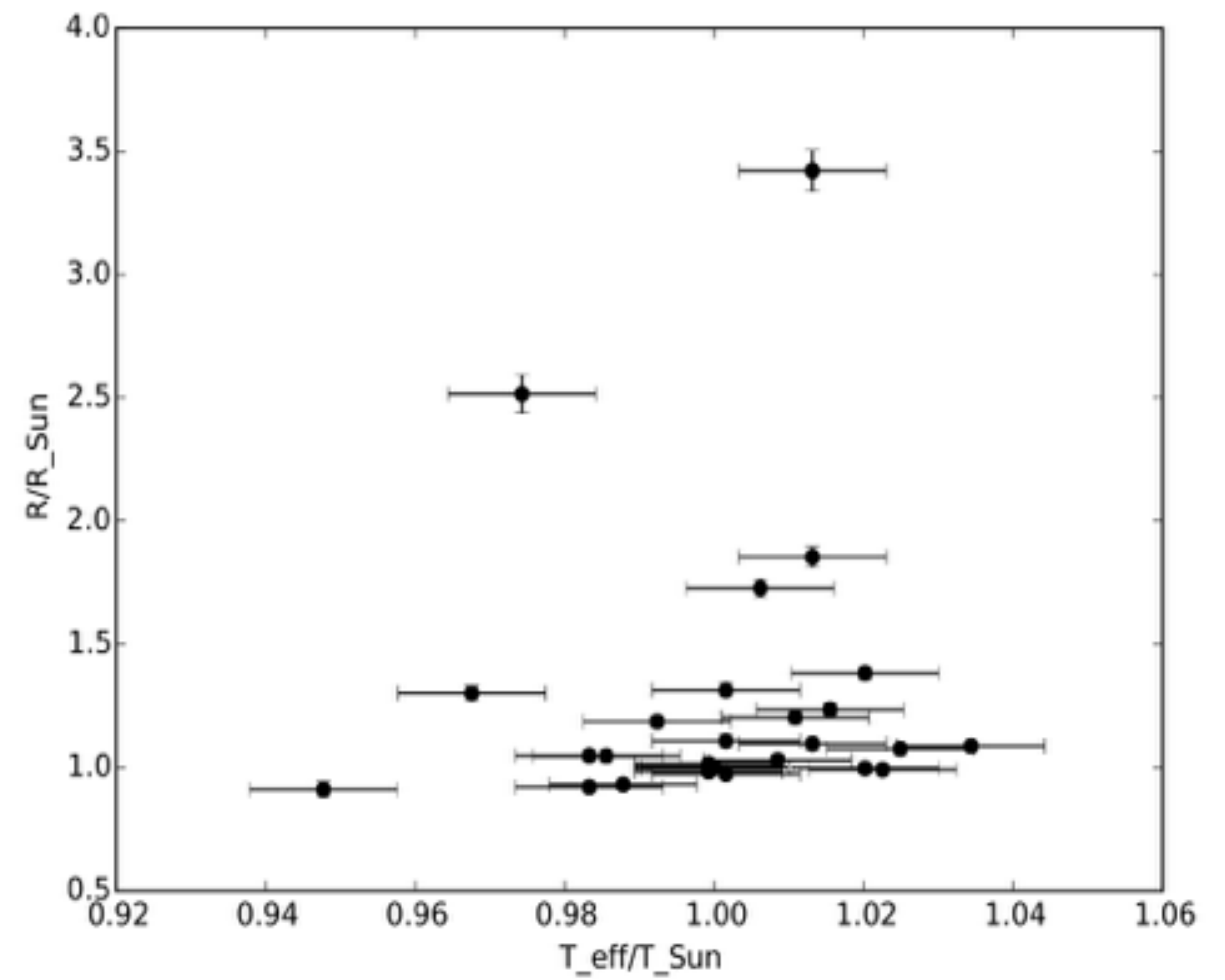
Lowell Obs.
SSS
(1994–2016)



“Solar Analog”
0.59 < (B-V) < 0.69 || SpT G0–G5 (M ±10% M_{Sun})

Solar Analog Sample





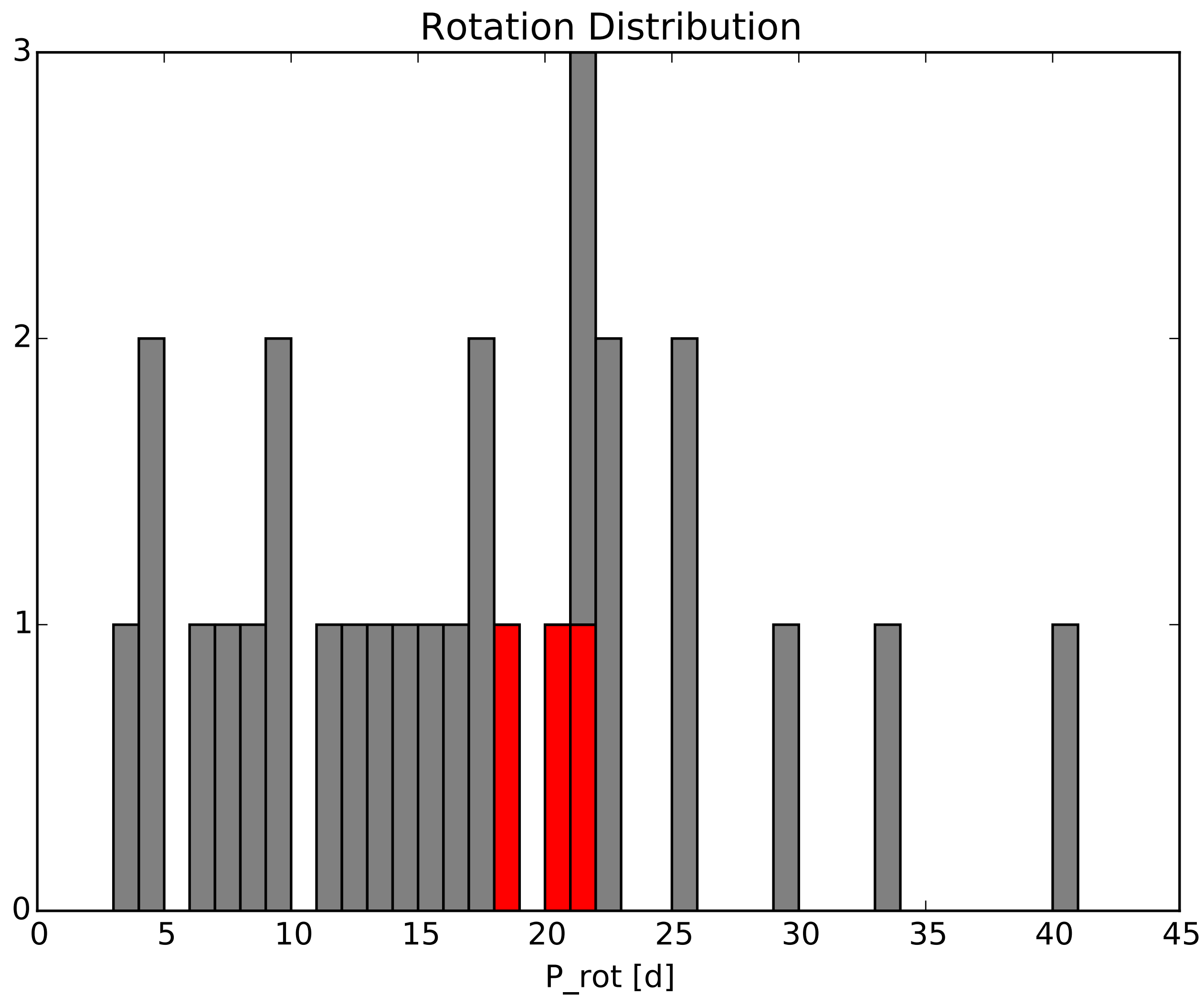
Source: Donahue et al.1996 + Baliunas et al. 1996

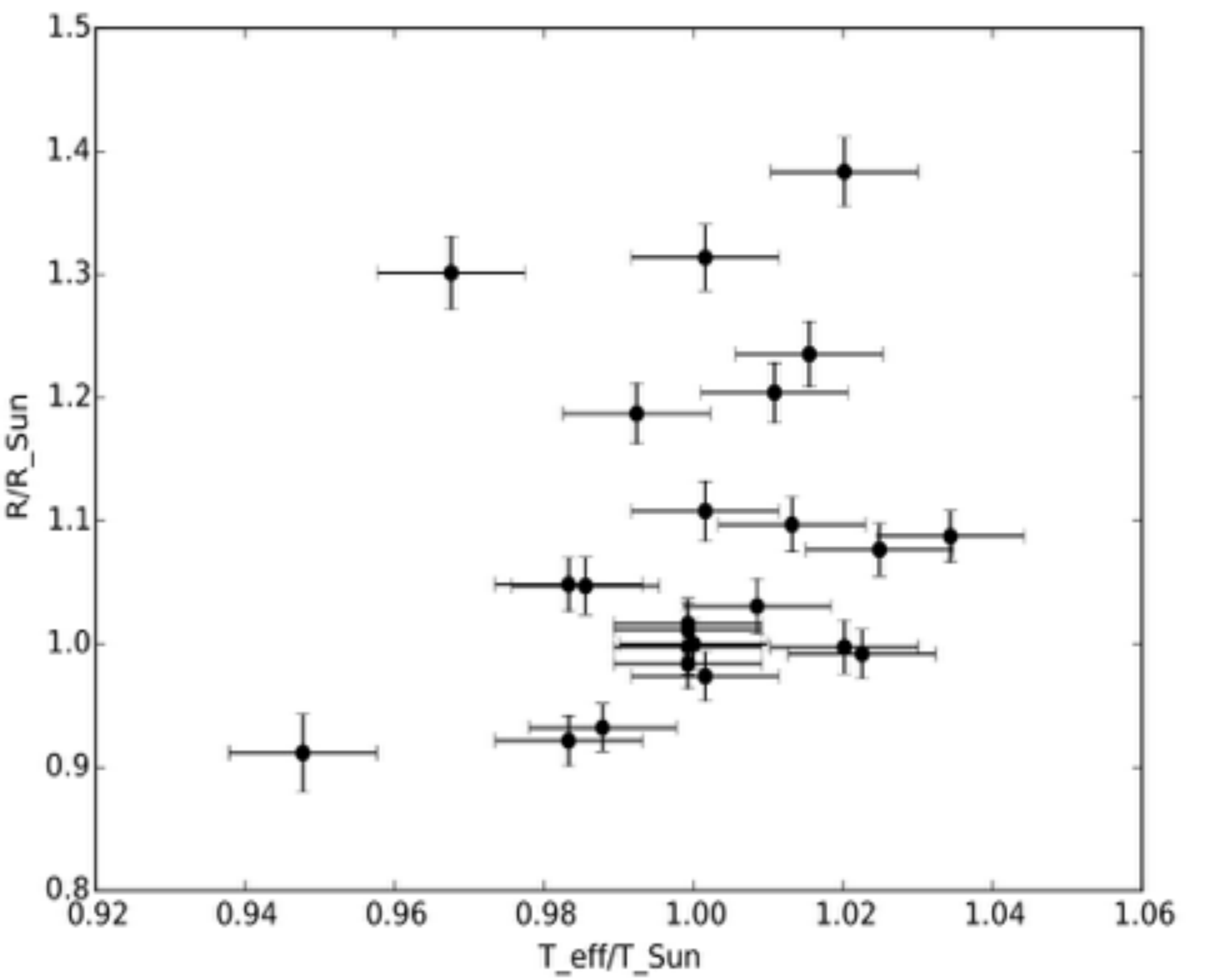
Method: rotational modulation of MWO S-index
red: v sin(i) → P_rot/sin(i)

Source: Geneva-Copenhagen Survey + *Hipparcos* distances + Flower 1996 bolometric corrections

Method: Strömgren photometry + infrared flux model + basic astronomy

Solar Analog Sample





Source: Donahue et al.1996 + Baliunas et al. 1996

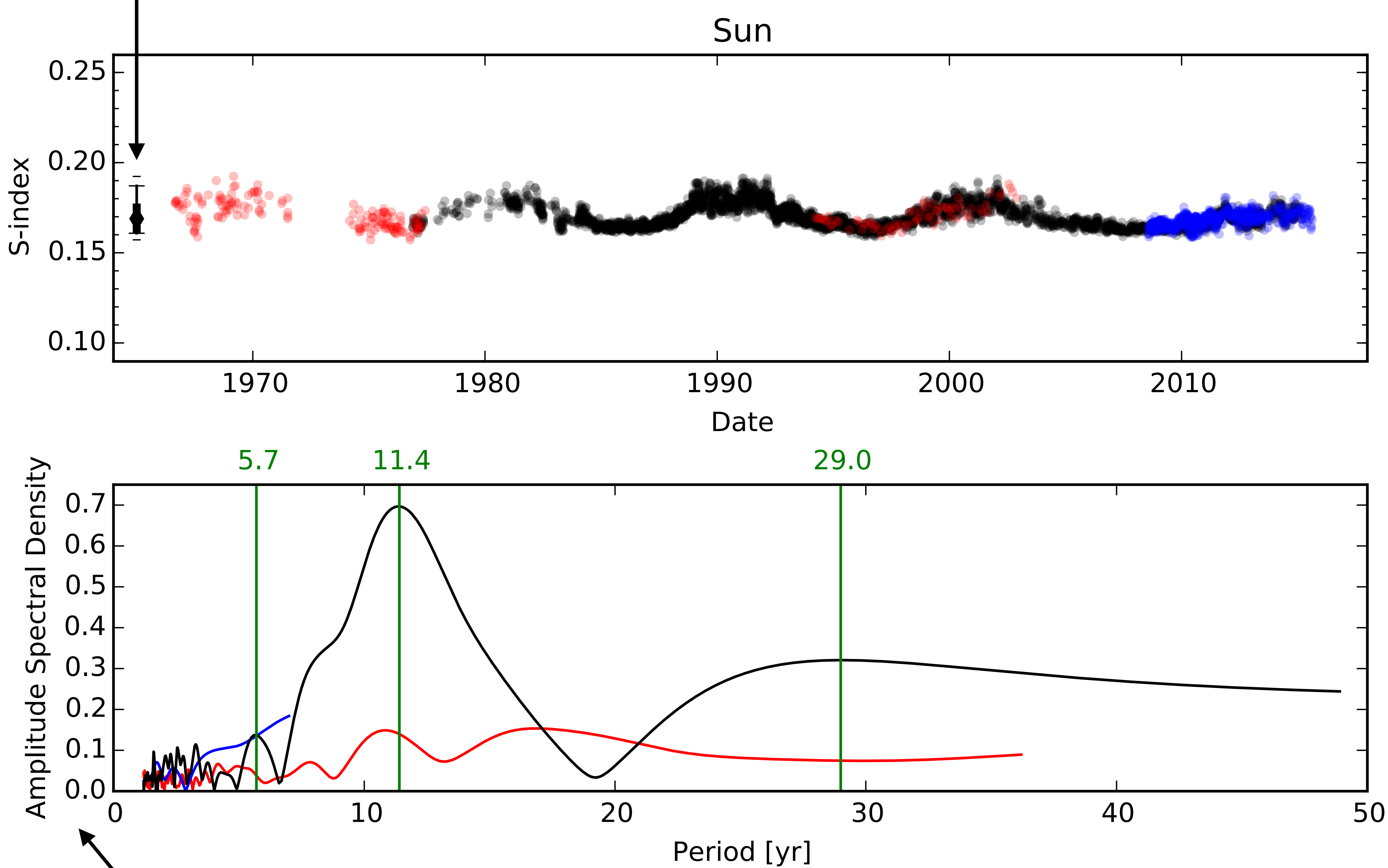
Method: rotational modulation of MWO S-index
red: v sin(i) → P_rot/sin(i)

Source: Geneva-Copenhagen Survey + *Hipparcos* distances + Flower 1996 bolometric corrections

Method: Strömgren photometry + infrared flux model + basic astronomy

Our Star

Amplitudes

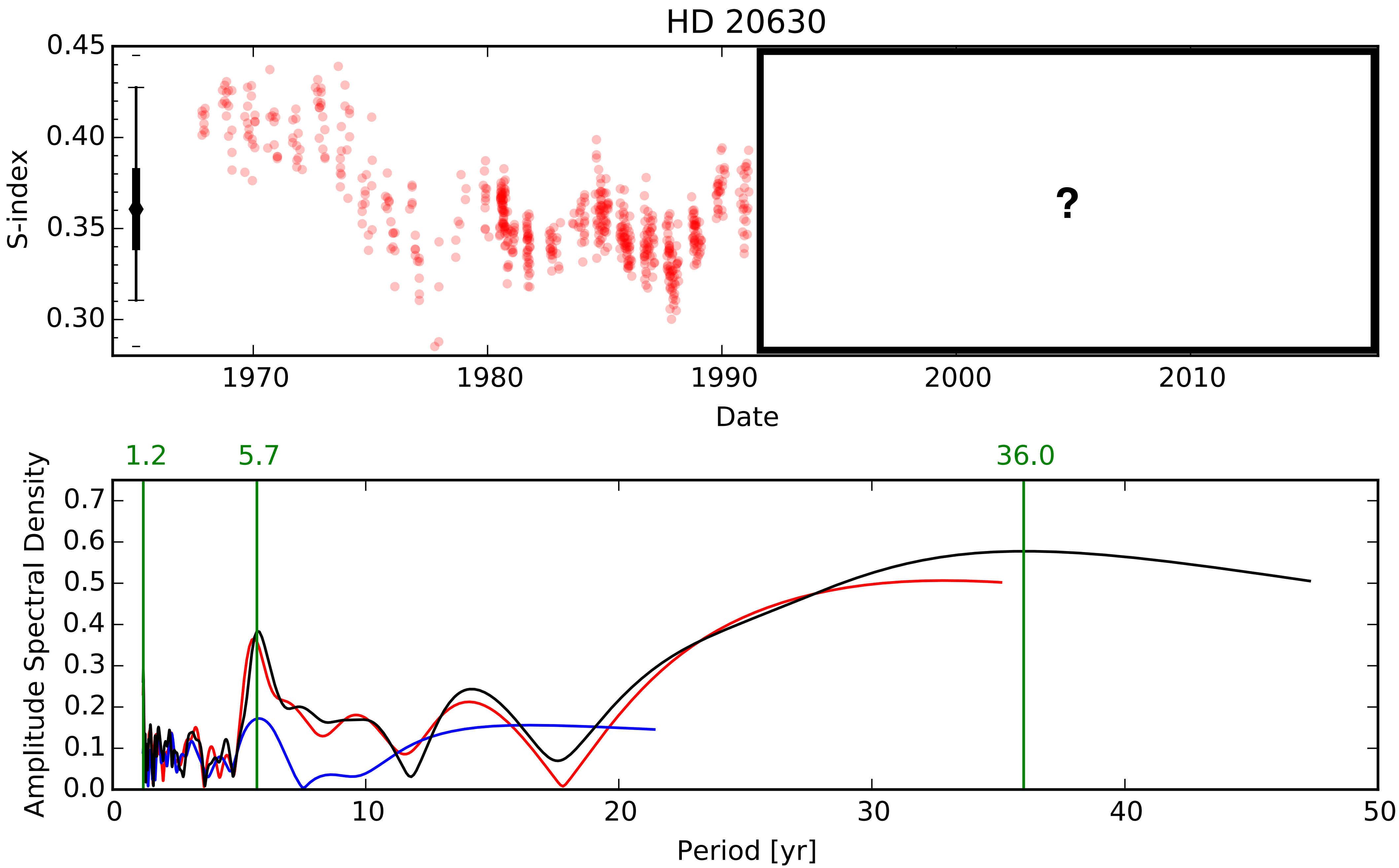


T_{eff}	1
R	1
L	1
P_{rot}	26
[Fe/H]	0
$\bar{S}$	0.169
A_{98}	0.026
$\bar{A}_{98,s}$	0.013
P_{var}	11.4
Q_{cyc}	**59**

RMS amp. in σ units

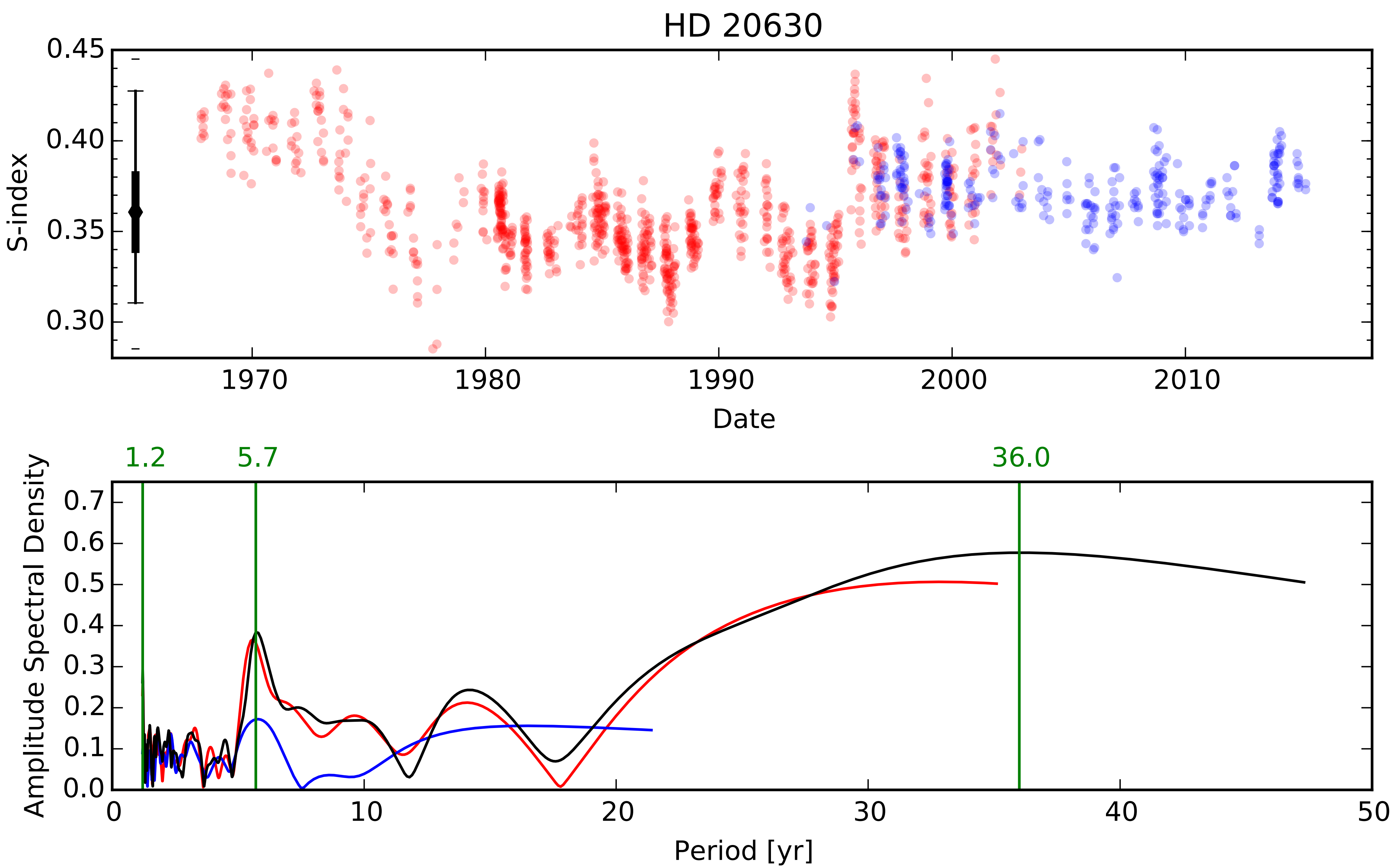
$Q_{cyc} = 100\ (1 - 0.5\ P_{var}/T)\ A$

Highly Variable Star



T_{eff}	0.99
R	0.93
L	0.83
P_{rot}	9.24
[Fe/H]	0.00
S	0.361
A_{98}	0.117
$\bar{A}_{98,s}$	0.041
P_{var}	5.7;36
Q_{cyc}	36;36

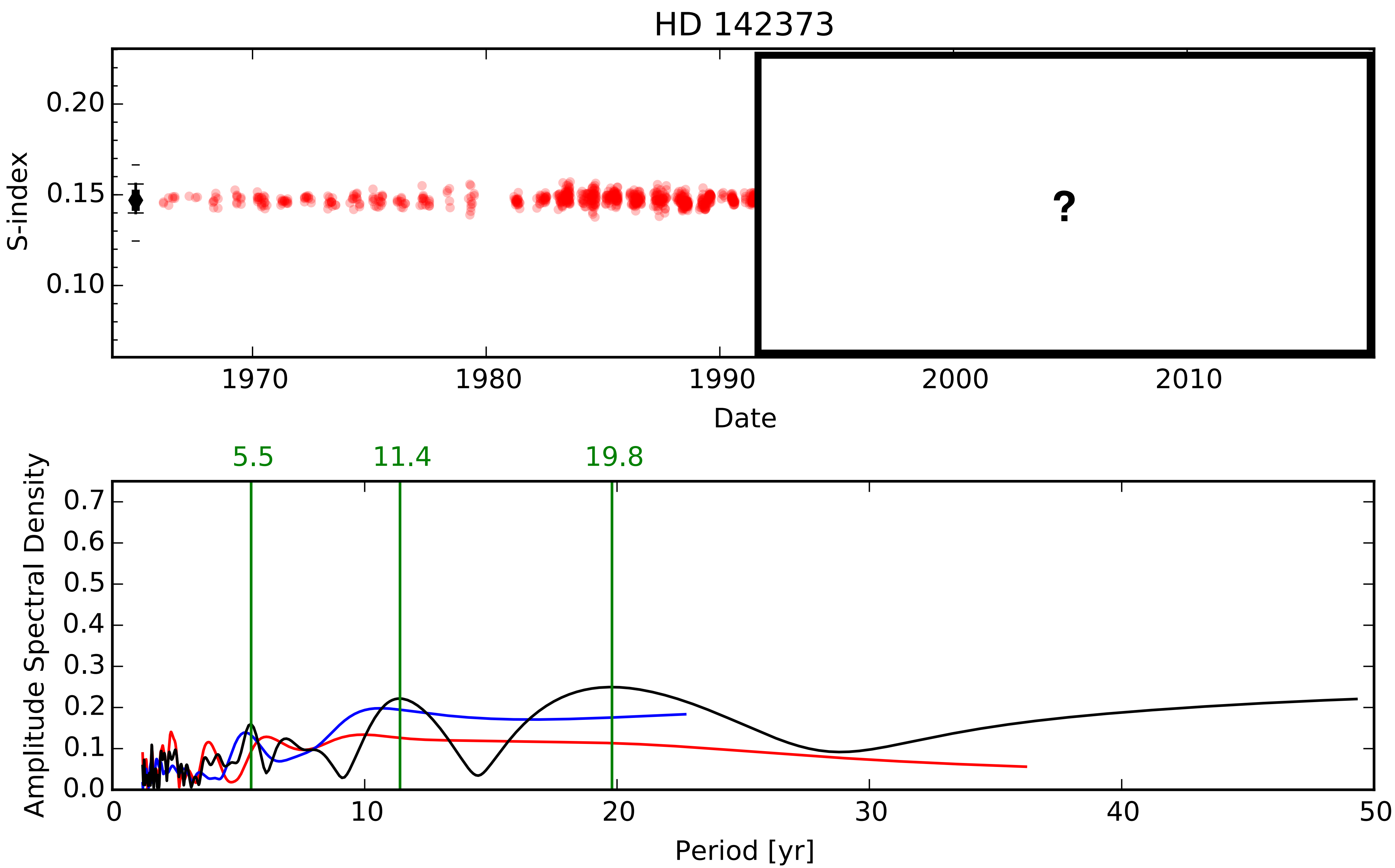
Highly Variable Star



T_{eff}	0.99
R	0.93
L	0.83
P_{rot}	9.24
[Fe/H]	0.00

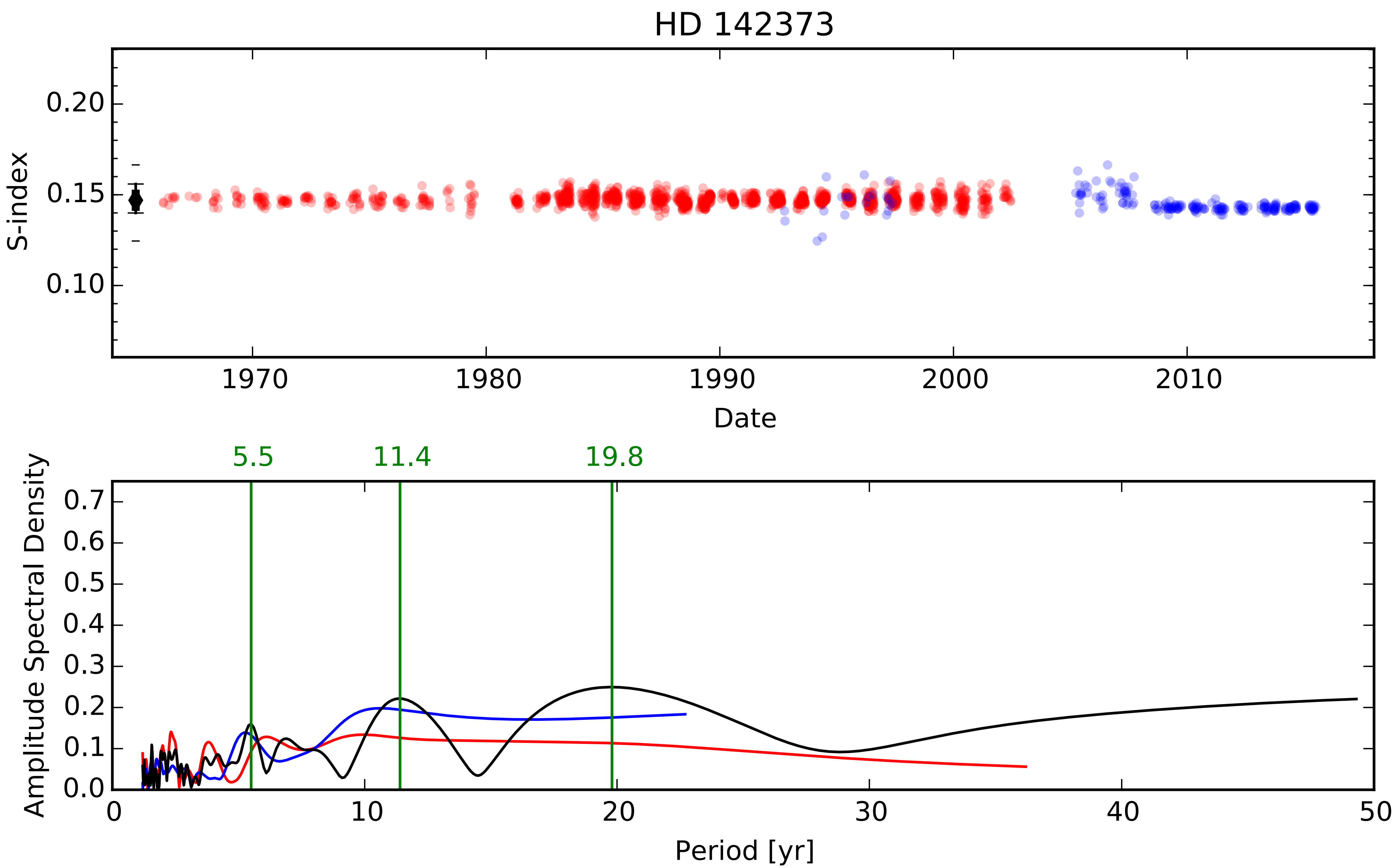
S	0.361
A_{98}	0.117
$\bar{A}_{98,s}$	0.041
P_{var}	5.7;36
Q_{cyc}	36;36

Flat Activity Star



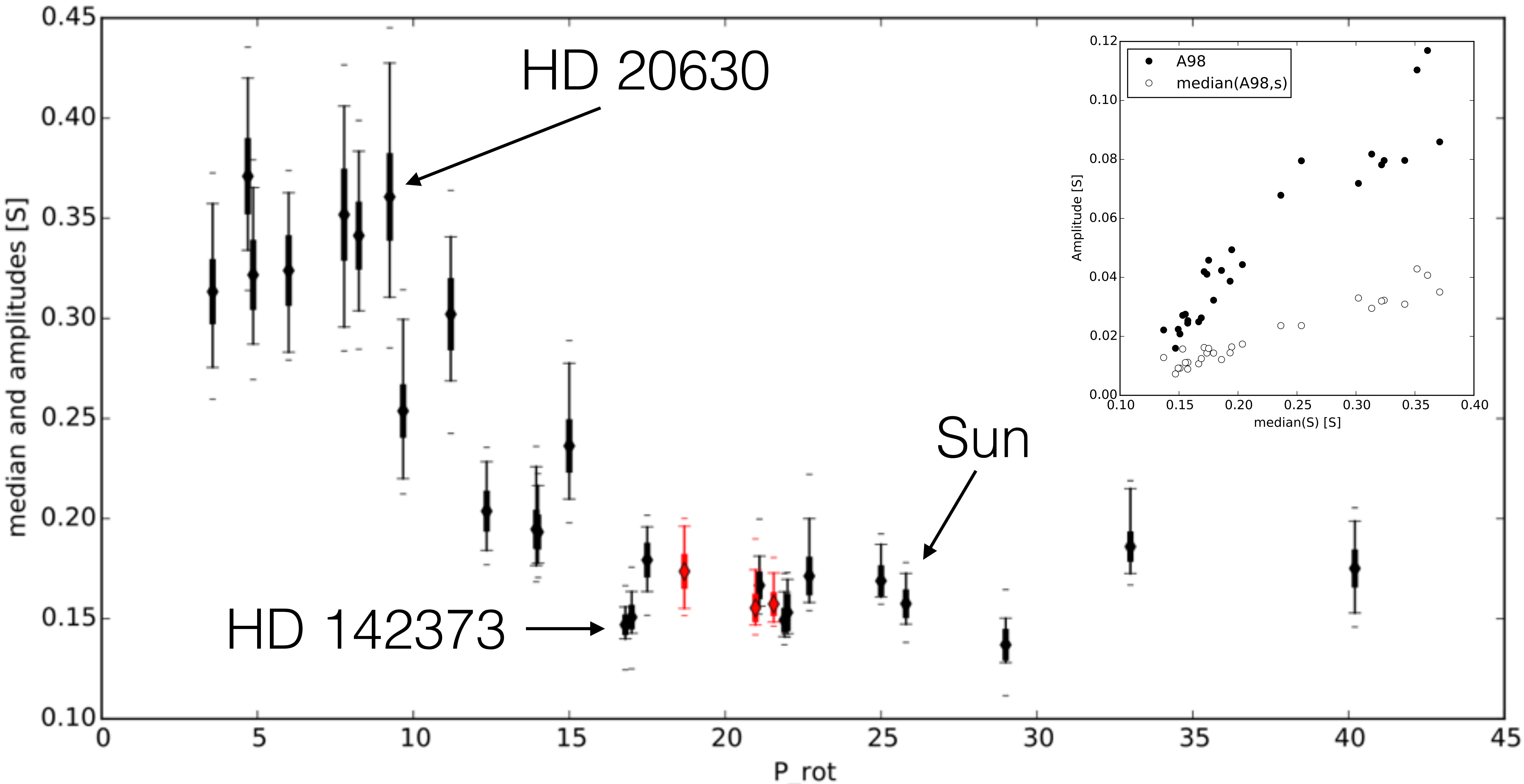
T_{eff}	1.01
R	1.73
L	3.06
P_{rot}	16.8
[Fe/H]	-0.50
$\bar{S}$	0.147
A_{98}	0.016
$\bar{A}_{98,s}$	0.007
P_{var}	–
Q_{cyc}	–

Flat Activity Star



T_{eff}	1.01
R	1.73
L	3.06
P_{rot}	16.8
[Fe/H]	-0.50
$\bar{S}$	0.147
A_{98}	0.016
$\bar{A}_{98,s}$	0.007
P_{var}	–
Q_{cyc}	–

Activity, Amplitude, and Rotation



Can this scatter be consistently explained?

Stellar Twin Search

Euclidean Distance:

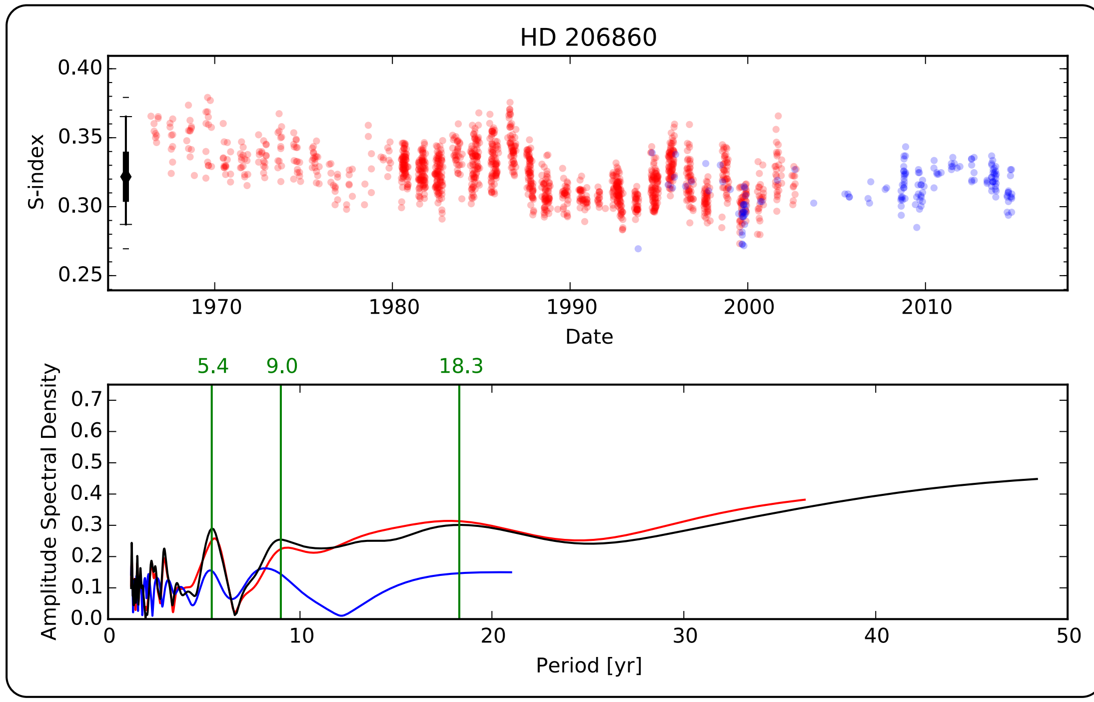
$$\mathrm{d}(\mathbf{p},\mathbf{q}) = \mathrm{d}(\mathbf{q},\mathbf{p}) = \sqrt{(q_1-p_1)^2 + (q_2-p_2)^2 + \cdots + (q_n-p_n)^2}$$

$$= \sqrt{\sum_{i=1}^{n}(q_i-p_i)^2}.$$

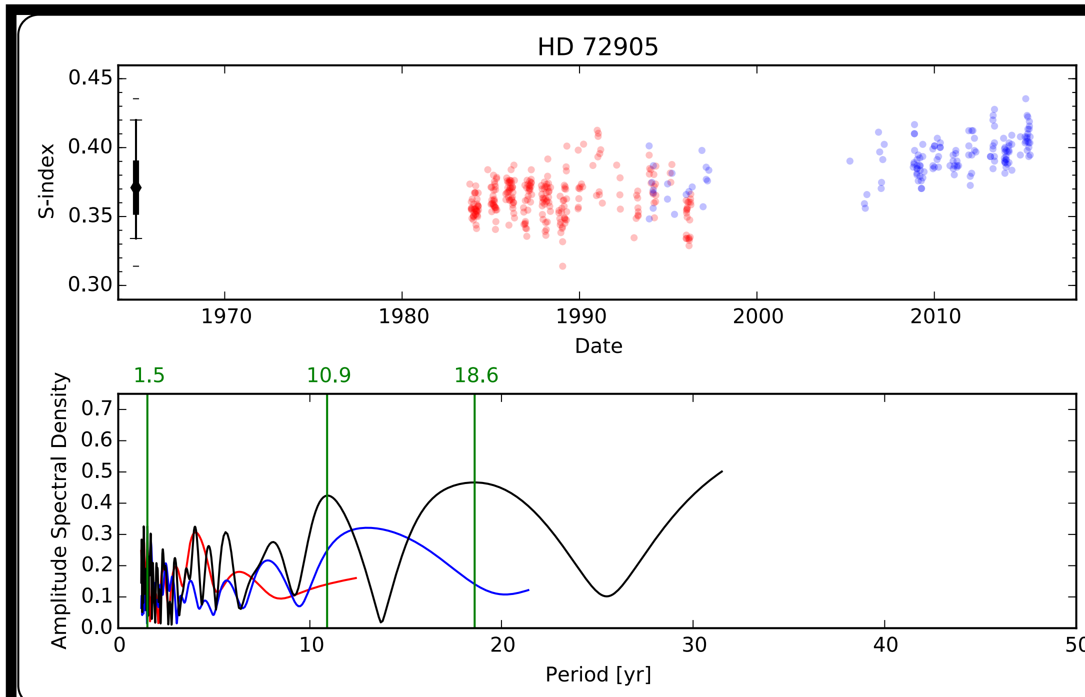
Parameter Vector is (T_{eff}, R, P_{rot}).
All expressed in solar units.
Allows us to sort stars by similarity.

T_eff, R all within 2%
P_rot from 3.5-6 days

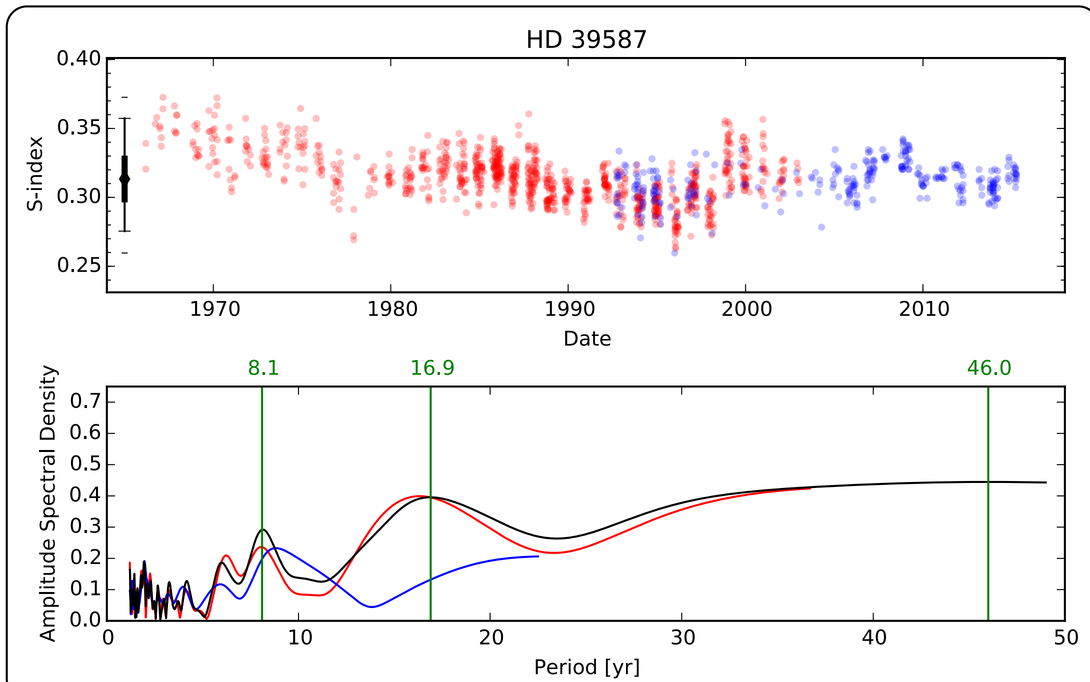
16% higher **median** activity
not the fastest rotator



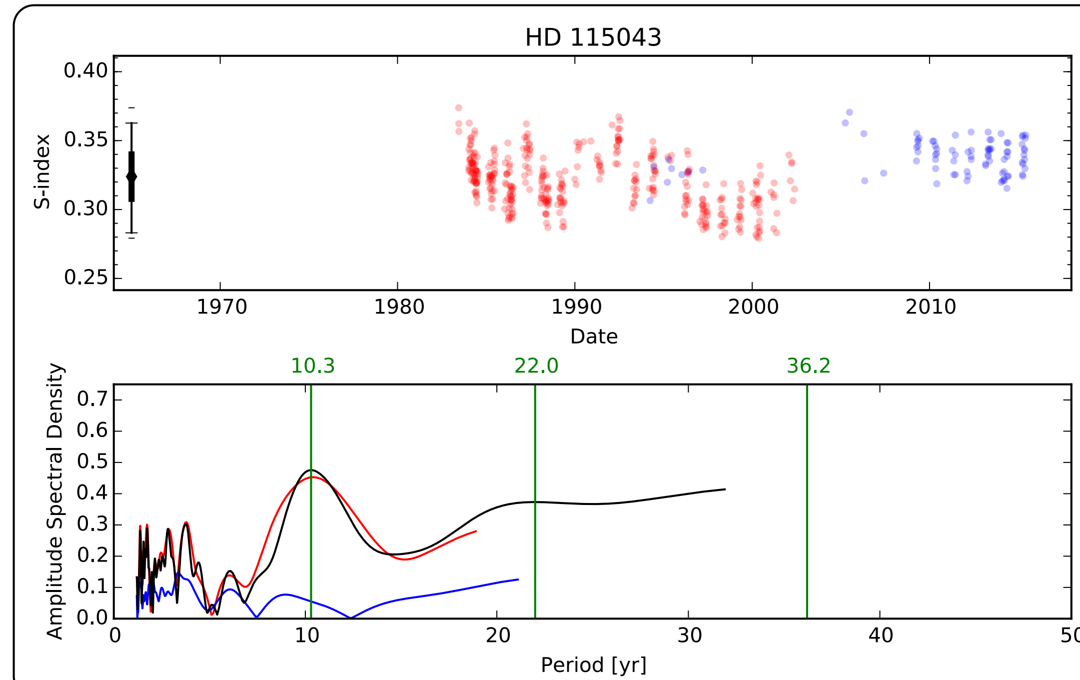
T_{eff}	1.02
R	1.00
L	1.08
P_{rot}	4.86
[Fe/H]	-0.19
$\bar{S}$	0.322
A_{98}	0.078
$\bar{A}_{98,s}$	0.032
P_{var}	5.4;18
Q_{cyc}	27;24



T_{eff}	1.00
R	0.98
L	0.97
P_{rot}	4.69
[Fe/H]	-0.25
$\bar{S}$	0.371
A_{98}	0.086
$\bar{A}_{98,s}$	0.035
P_{var}	–
Q_{cyc}	–

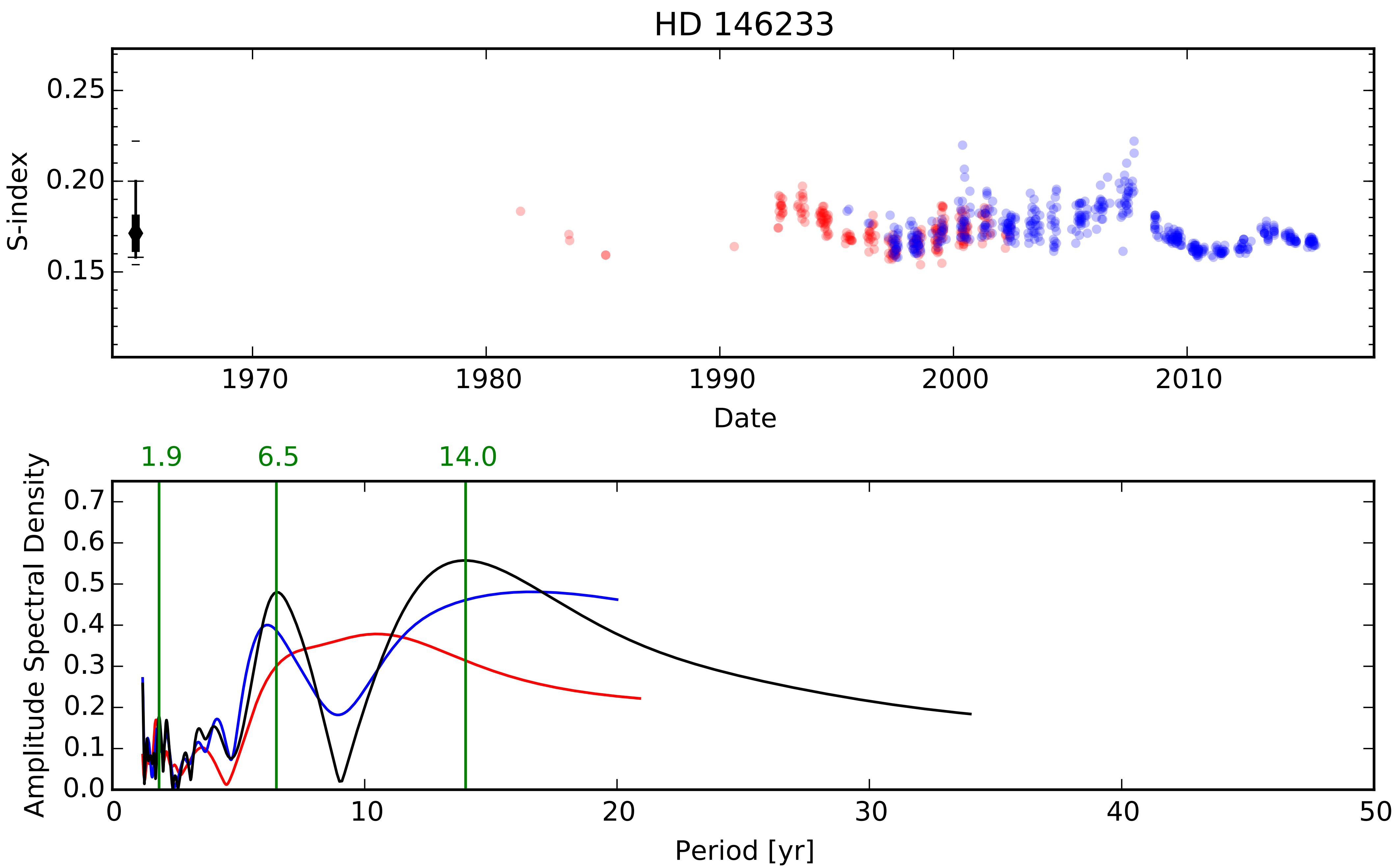


T_{eff}	1.02
R	0.99
L	1.08
P_{rot}	3.56
[Fe/H]	-0.16
$\bar{S}$	0.313
A_{98}	0.082
$\bar{A}_{98,s}$	0.030
P_{var}	17;8.1
Q_{cyc}	33;27



T_{eff}	1.00
R	1.01
L	1.02
P_{rot}	6
[Fe/H]	-0.22
$\bar{S}$	0.324
A_{98}	0.080
$\bar{A}_{98,s}$	0.032
P_{var}	10.3
Q_{cyc}	40

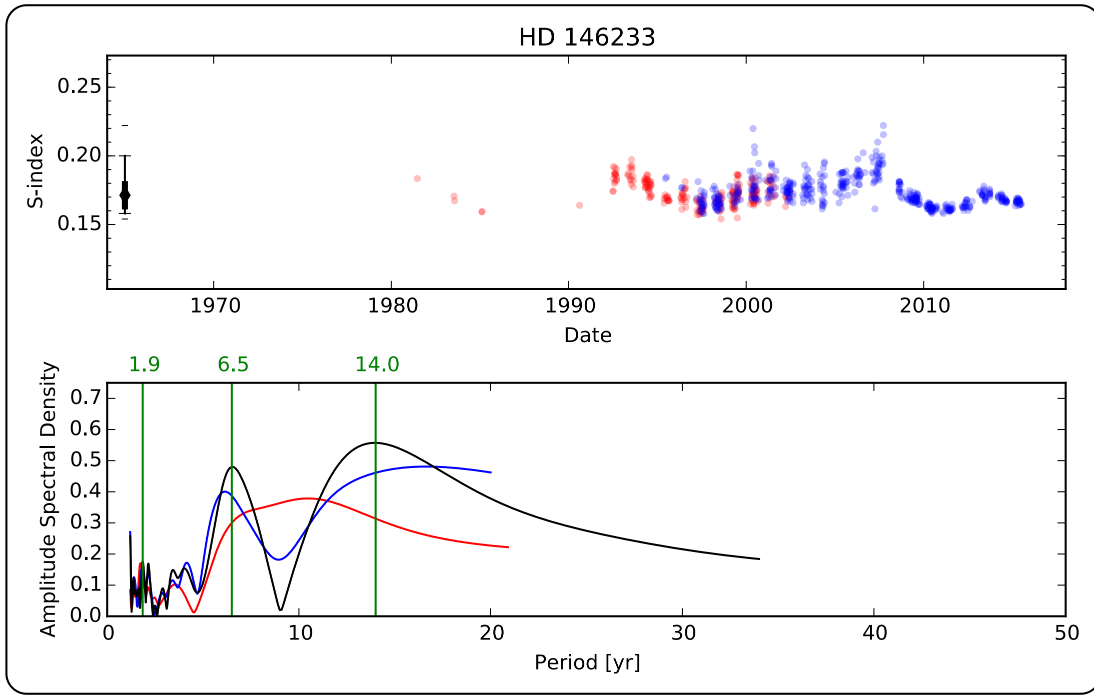
18 Sco: The Solar Twin



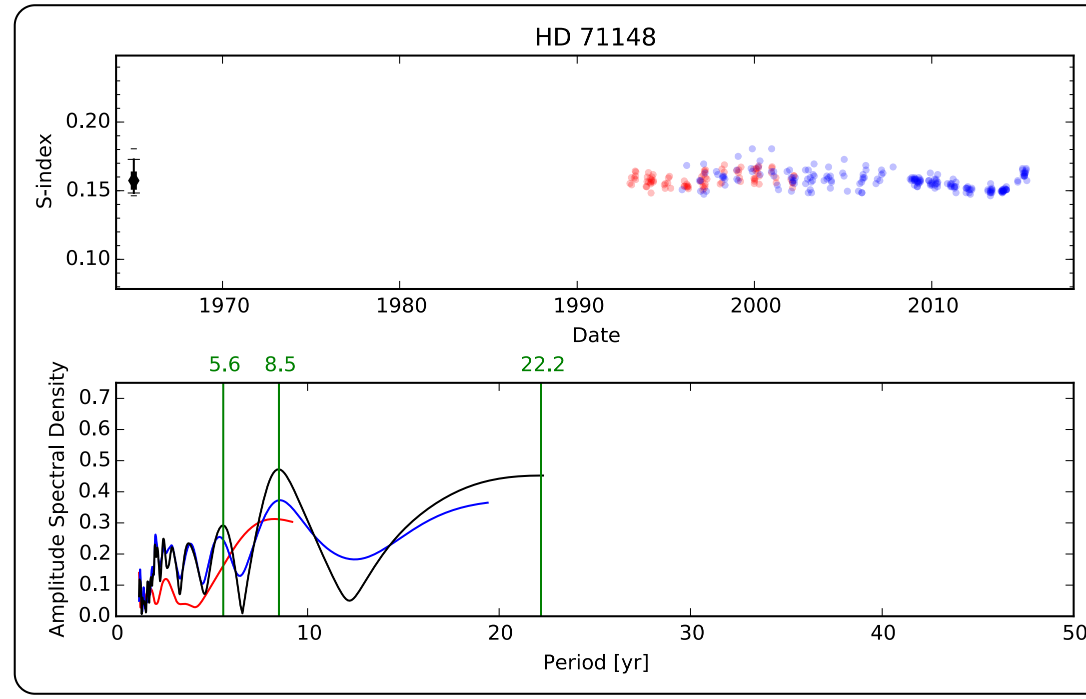
T_{eff}	1.00
R	1.02
L	1.03
P_{rot}	22.7
[Fe/H]	-0.02

$\bar{S}$	0.171
A_{98}	0.042
$\bar{A}_{98,s}$	0.016
P_{var}	14;6.5
Q_{cyc}	44;43

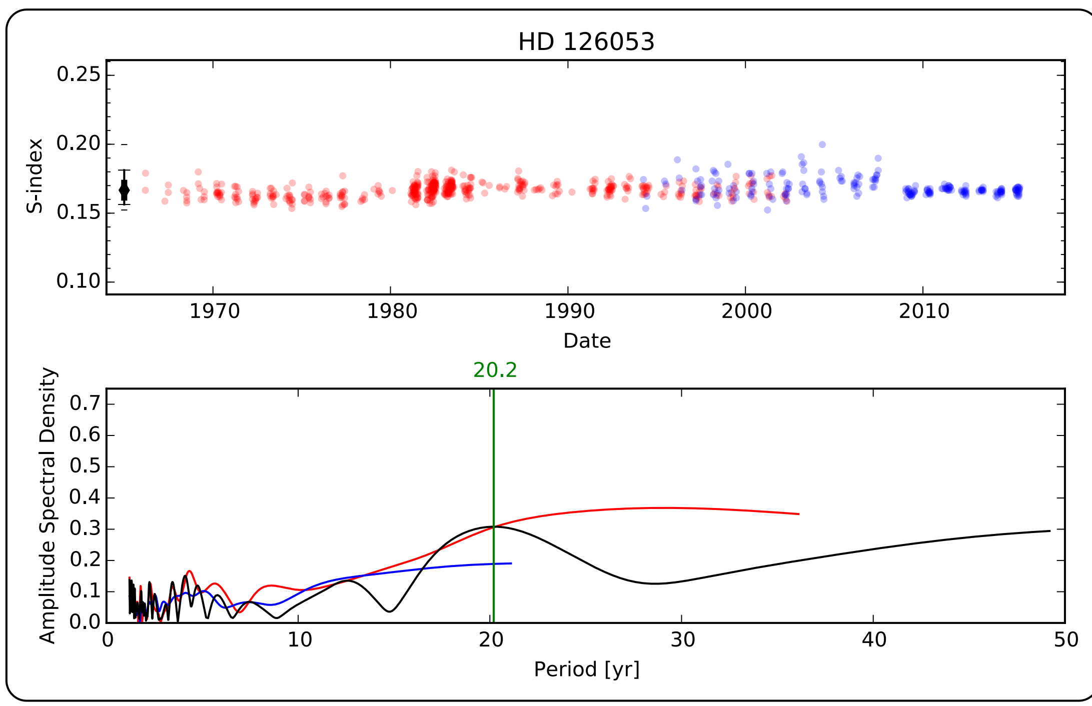
Top 4 Most Similar to the Sun



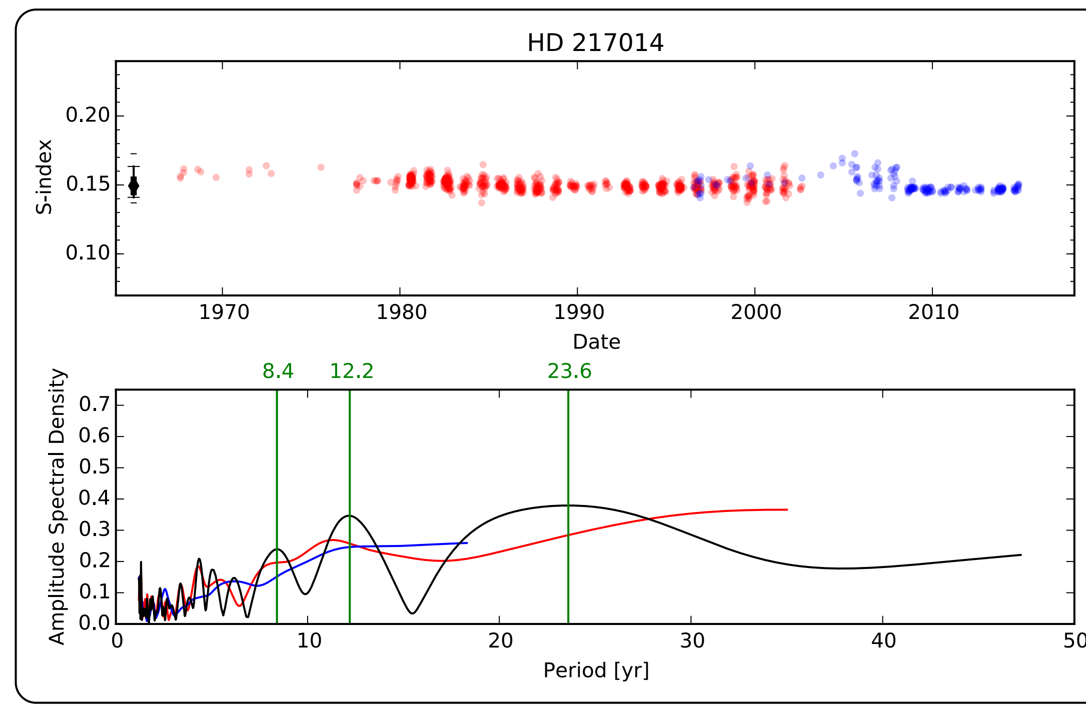
T_{eff}	1.00
R	1.02
L	1.03
P_{rot}	22.7
[Fe/H]	-0.02
$\bar{S}$	0.171
A_{98}	0.042
$\bar{A}_{98,s}$	0.016
P_{var}	14;6.5
Q_{cyc}	44;43



T_{eff}	1.00
R	1.11
L	1.24
P_{rot}	>21.6
[Fe/H]	-0.10
$\bar{S}$	0.157
A_{98}	0.025
$\bar{A}_{98,s}$	0.009
P_{var}	8.5
Q_{cyc}	38



T_{eff}	0.98
R	0.92
L	0.79
P_{rot}	21.1
[Fe/H]	-0.39
$\bar{S}$	0.167
A_{98}	0.025
$\bar{A}_{98,s}$	0.011
P_{var}	20.2
Q_{cyc}	25



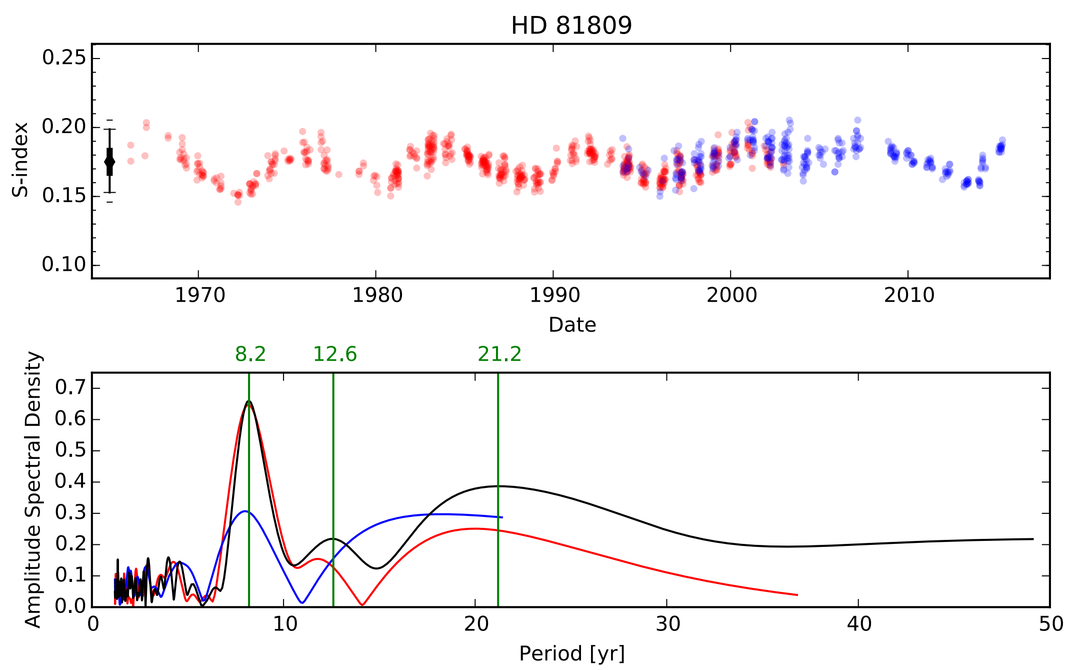
T_{eff}	0.99
R	1.19
L	1.37
P_{rot}	21.9
[Fe/H]	+0.12
$\bar{S}$	0.149
A_{98}	0.022
$\bar{A}_{98,s}$	0.009
P_{var}	12.2
Q_{cyc}	30

P_rot within 12%, wide range of metallicities, radii

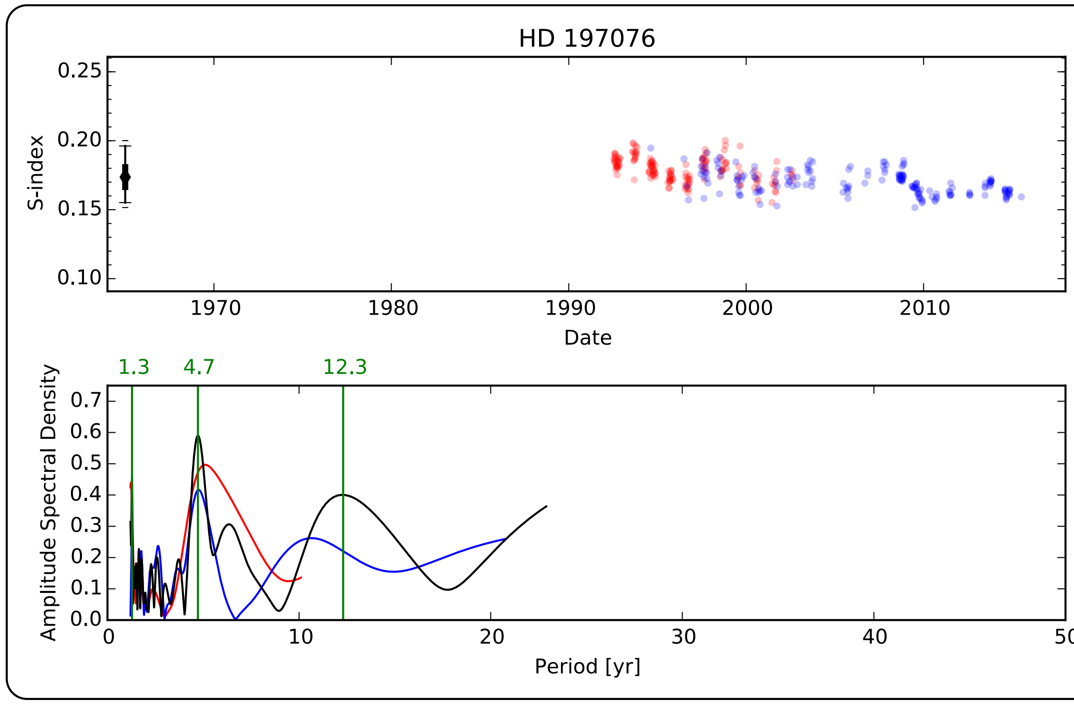
Cycles and “Cycles”

Q_{cyc}	$P_{var,1}$	$P_{var,2}$
> 50 “Excellent”	3	0
40-50 “Good”	5	1
30-40 “Fair”	10	6
20-30 “Poor”	5	3
< 20 “No Cycle”	5	18

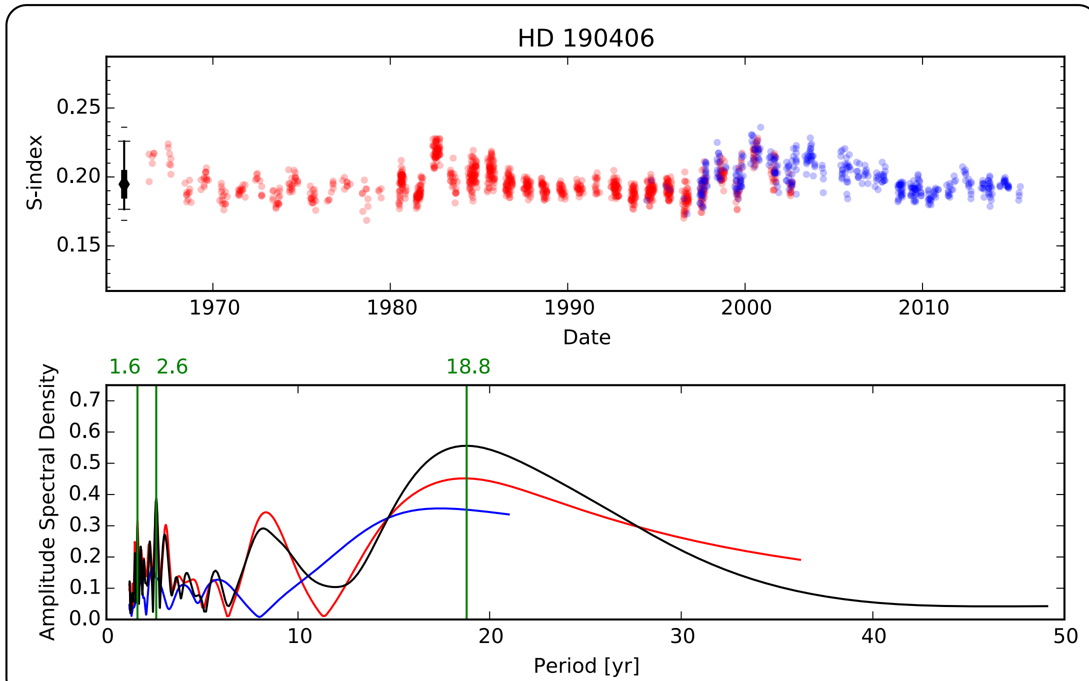
Top 4 Cycles



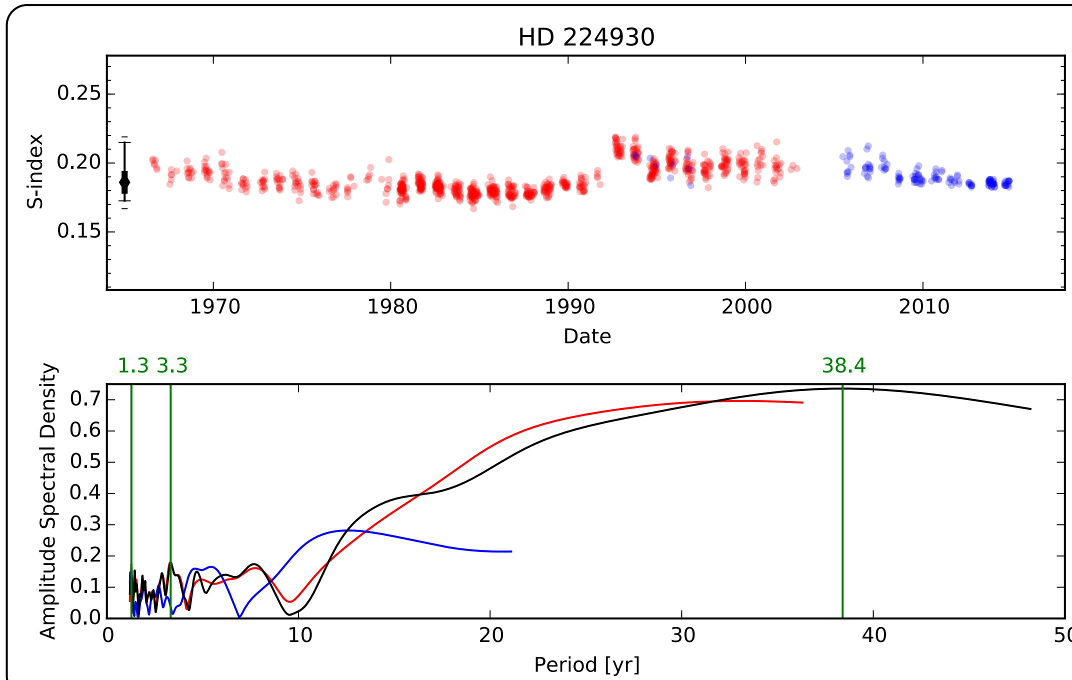
B-V	0.638 0.654	
mass	1.7 1.0	
M_V	2.88 4.77	
P_{rot}	40.2	
[Fe/H]	-0.29	
$\bar{S}$	0.175	
A_{98}	0.049	
$\bar{A}_{98,s}$	0.016	
P_{var}	8.2	
Q_{cyc}	**61**	



T_{eff}	1.00
R	1.00
L	0.99
P_{rot}	>18.7
[Fe/H]	-0.22
$\bar{S}$	0.174
A_{98}	0.041
$\bar{A}_{98,s}$	0.014
P_{var}	4.7
Q_{cyc}	**53**



T_{eff}	1.01
R	1.10
L	1.27
P_{rot}	13.94
[Fe/H]	-0.12
$\bar{S}$	0.195
A_{98}	0.049
$\bar{A}_{98,s}$	0.016
P_{var}	19;2.6
Q_{cyc}	45;38

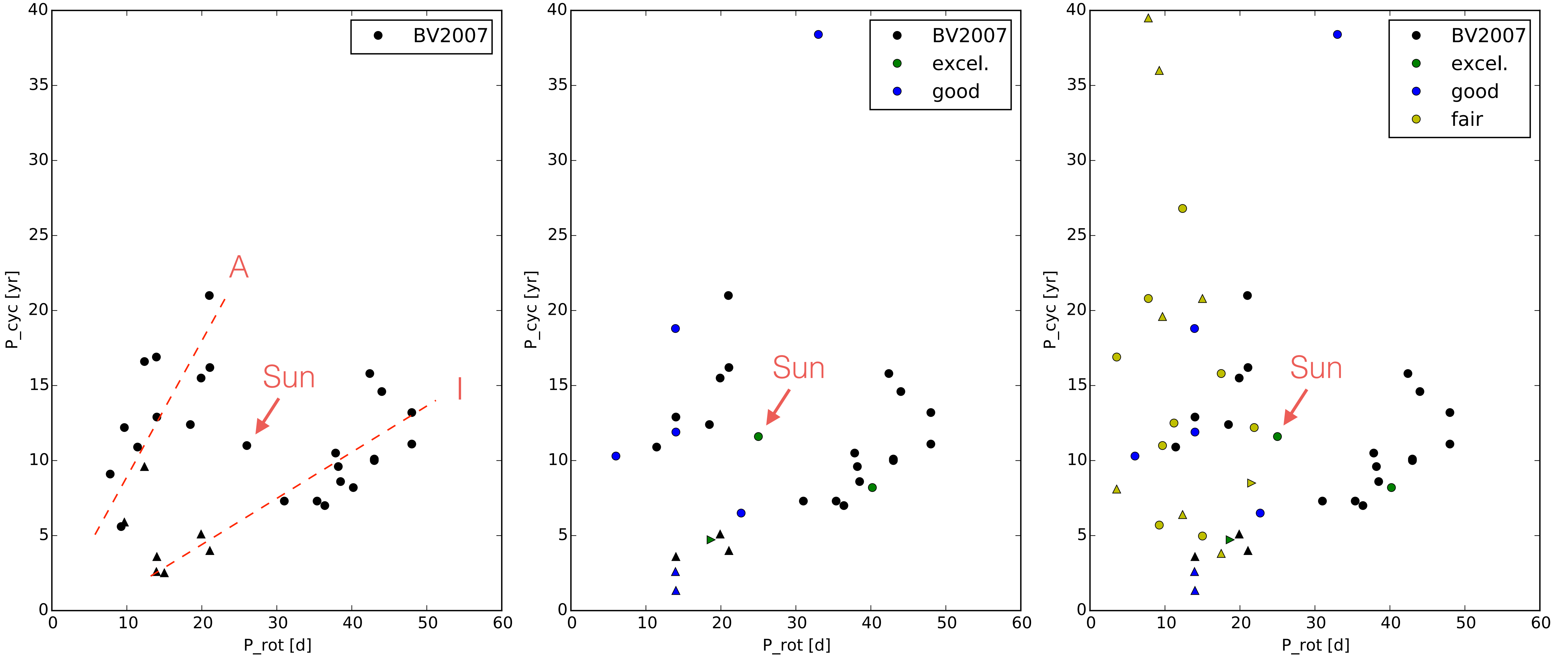


T_{eff}	0.95
R	0.91
L	0.67
P_{rot}	33
[Fe/H]	-0.78
$\bar{S}$	0.186
A_{98}	0.042
$\bar{A}_{98,s}$	0.012
P_{var}	38.4
Q_{cyc}	44

#5 is solar twin 18 Sco.

Cycle Period vs. Rotation

Bohm-Vitense 2007;
Saar & Brandenburg 1999



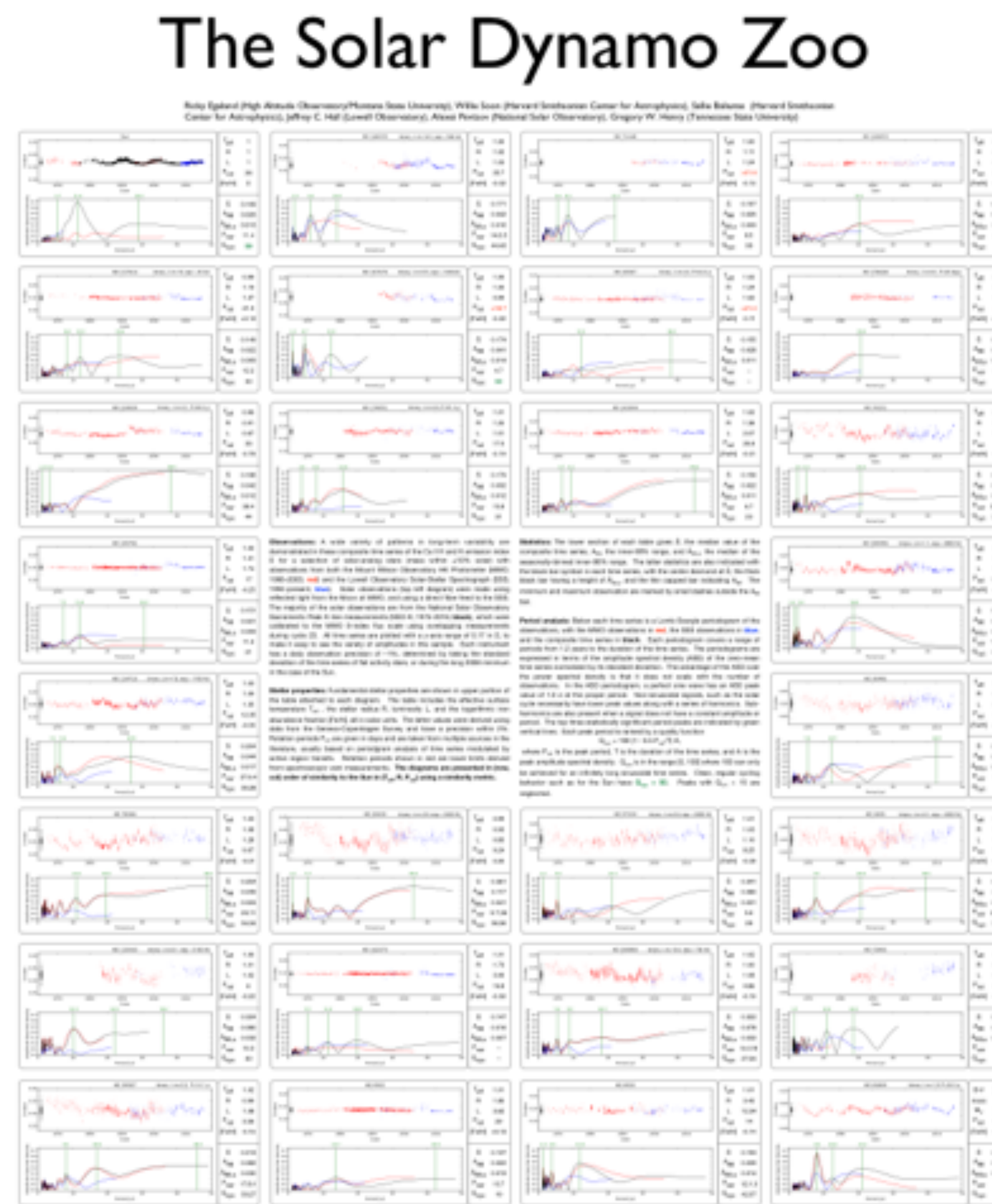
26 stars
F,G,K types

26 stars
(3 swaps)

36 stars

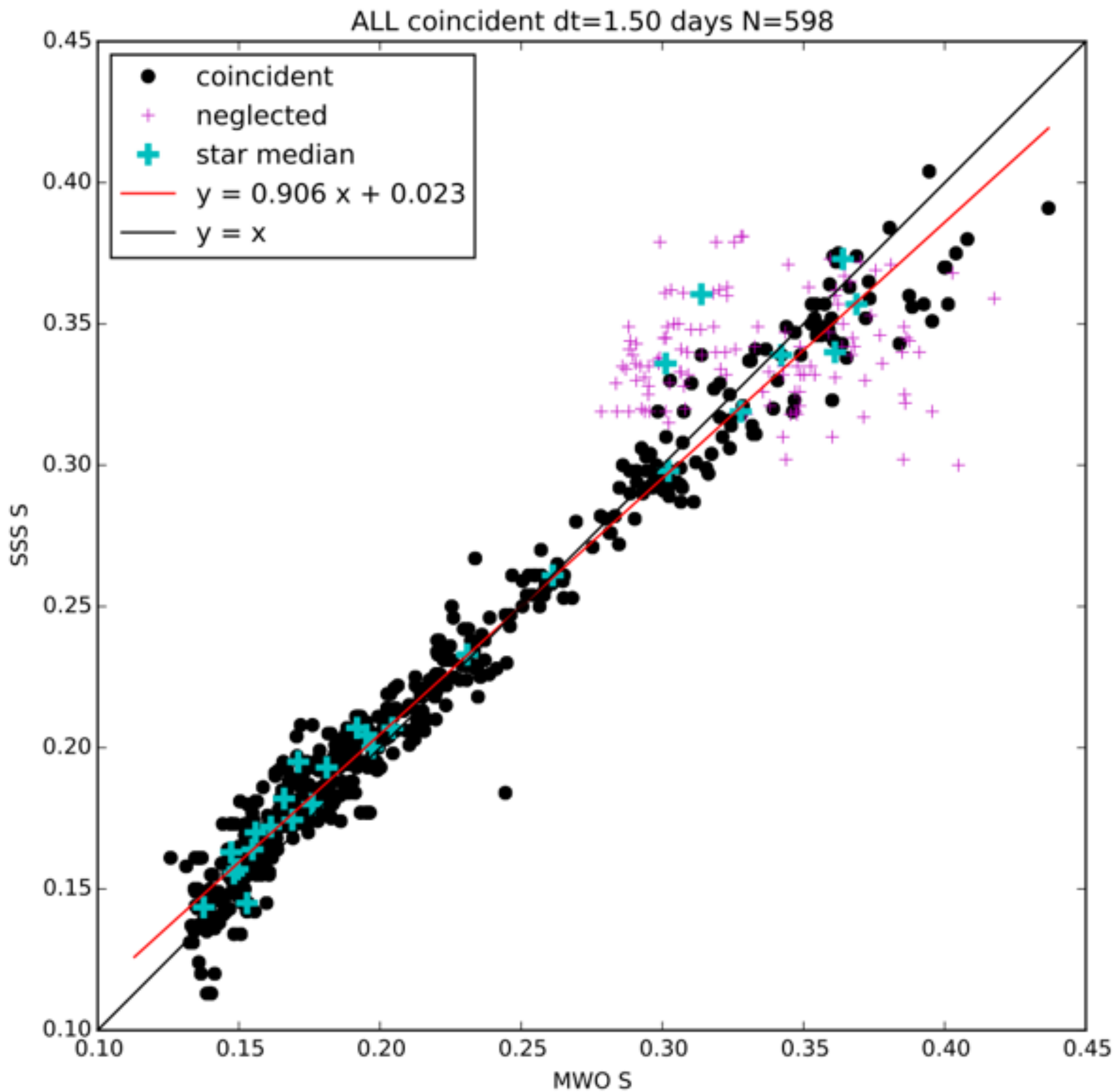
Conclusions

- 50-year stellar activity time series allow the detection of longer-term patterns of variability and further confirmation of flat activity stars.
- Fast rotating stars vary ~2x more in 1 year than the Sun does over its 11-year cycle. There are ~linear trends in amplitude vs. median activity.
- Very clear, clean cycles like the Sun are the minority in this sample of solar-analogs.
- Sun is still lonely in the P_cyc vs. P_rot diagram, but longer cycles make the situation even more complicated.



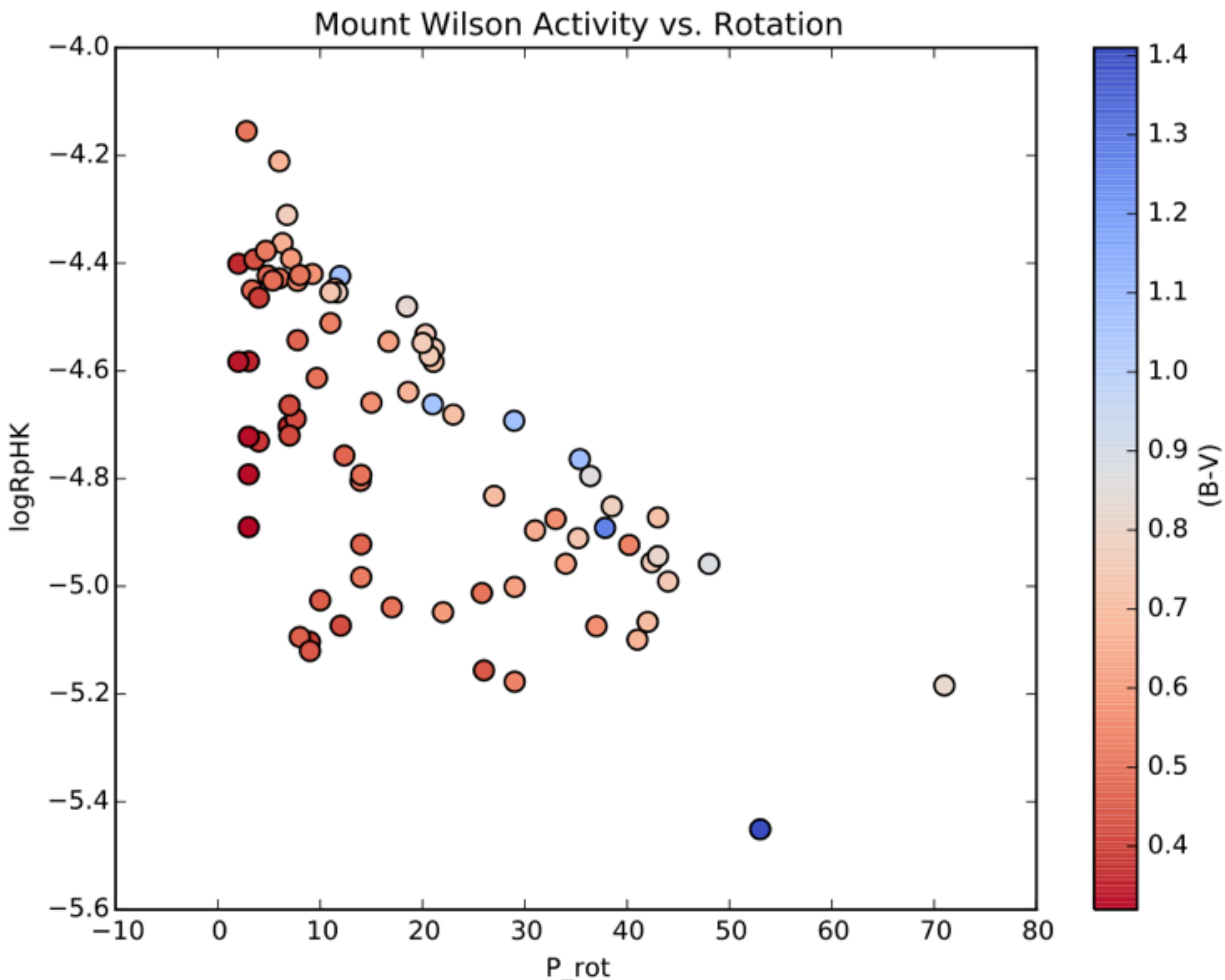
poster P11.03

Calibration



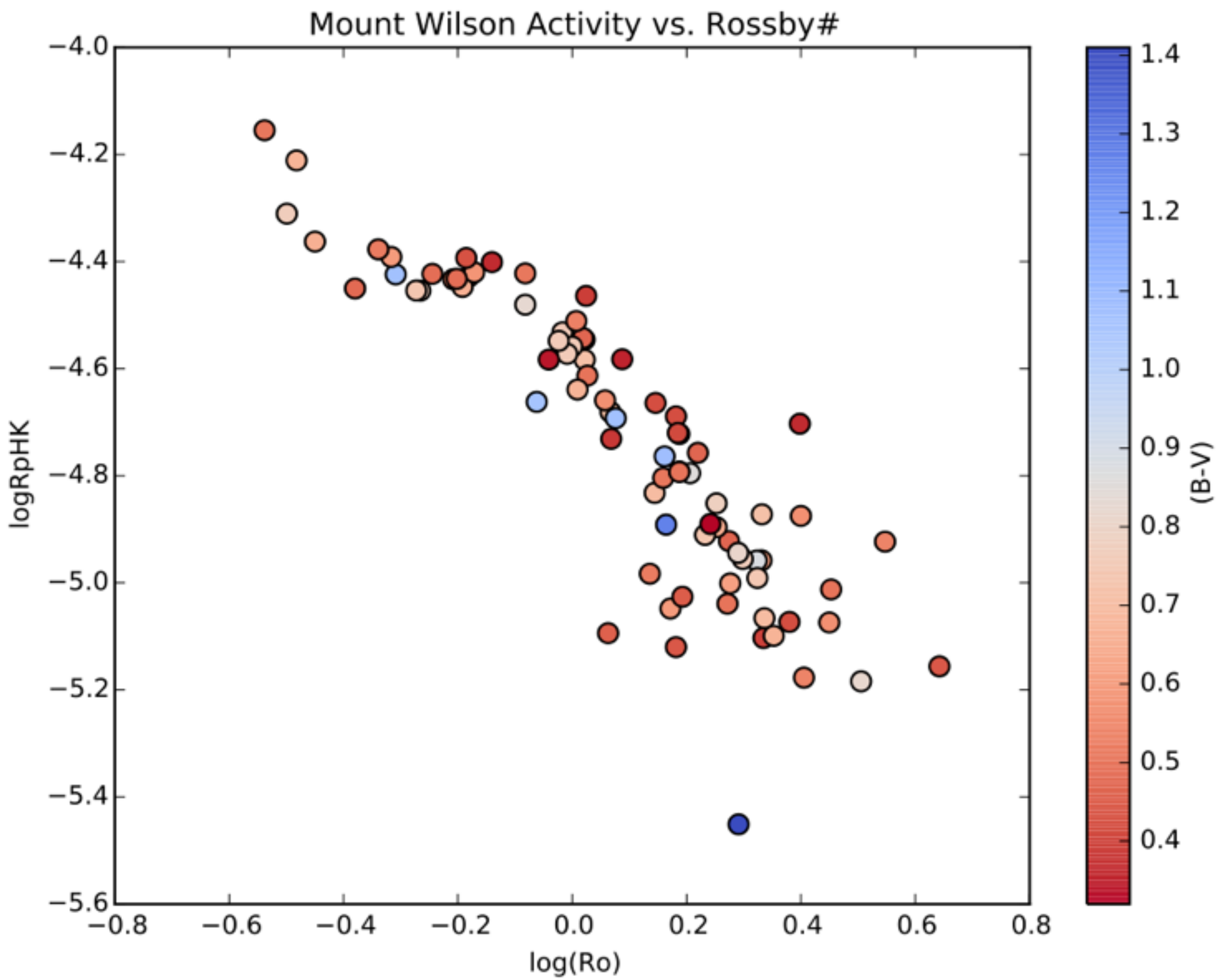
$$SSS_i = 0.906\ MWO_i + 0.023 + correction_i$$

Stellar Results



(Noyes et al. 1984 + Baliunas et al. 1996 + Donahue et al. 1996)

Stellar Results



(Noyes et al. 1984 + Baliunas et al. 1996 + Donahue et al. 1996)