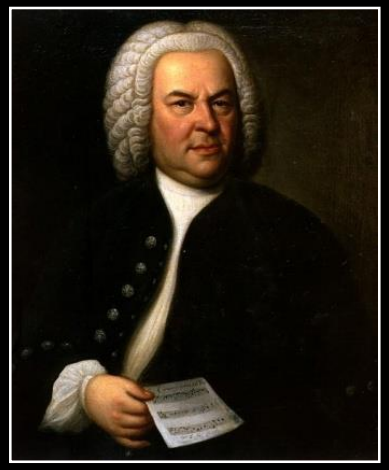
The Art of Science and the Physics of Sun-Like Stars

Jeffrey Hall
Lowell Observatory, Flagstaff, AZ

1 “An Excess of Art”
2 Sixty Years of Stargazing
3 Results & Case Studies
4 Prospects for the Future
5 “You were right”

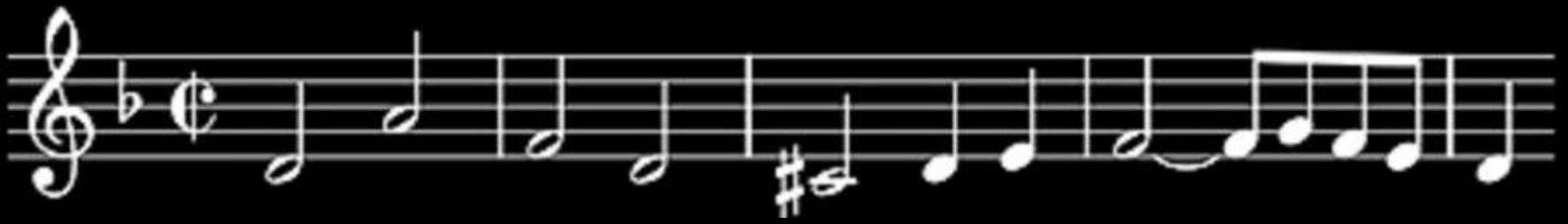


BACH (1685-1750)

"A list of Bach's achievements in musical science testifies to his emphatic and consistent application of the principles of counterpoint…"

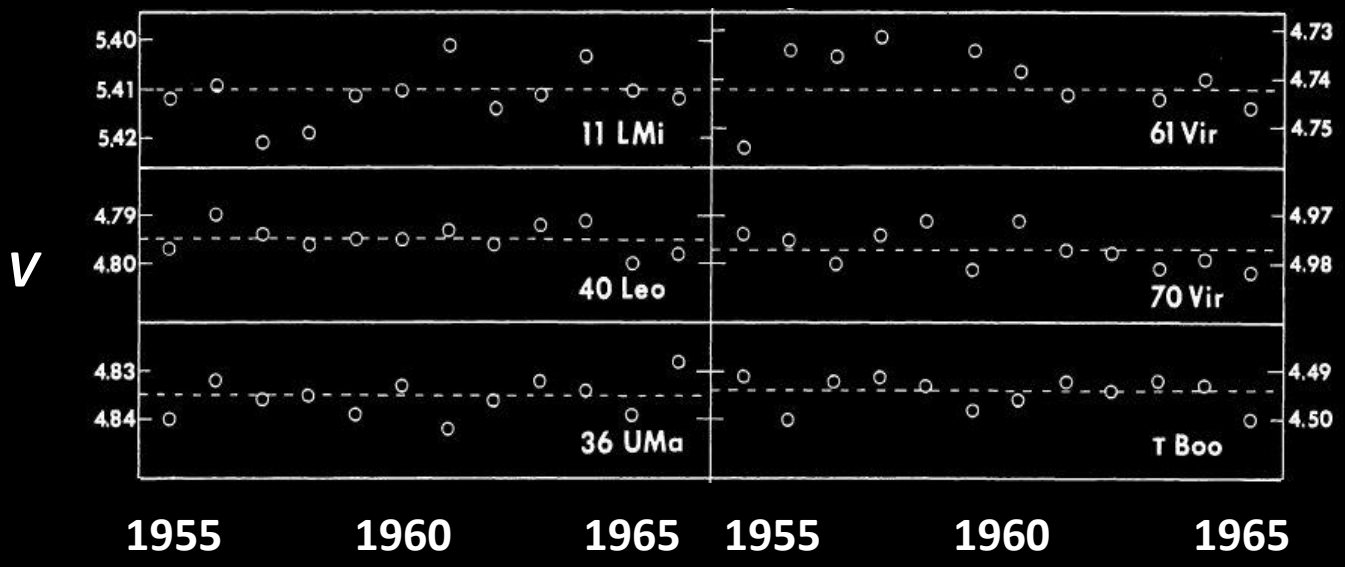
- Christoph Wolff

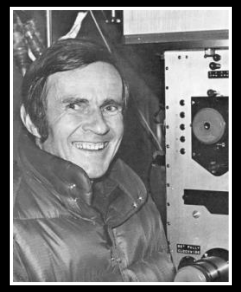
Die Kunst der Fuge (Main subject)



1 “An Excess of Art”
2 **Sixty Years of Stargazing**
3 Results & Case Studies
4 Prospects for the Future
5 “You were right”

1950-1966: Lowell photometry of Uranus/Neptune & solar analogs





"The present paper is the final report on the search for the solar variability conducted at the Lowell Observatory. No more observations of this kind are planned at this Observatory."[1]

[1] JERZYKIEWICZ & SERKOWSKI 1966 Low. Obs. Bull. **6** 295

1966-2003: The Mount Wilson HK Project

HD 1835 HD 81809 HD 142373

"Does the chromospheric activity of main-sequence stars vary with time, and if so, how?"[1]

"About 15% of the records are constant with time..."[2,3]

[1] WILSON 1978 ApJ **226** 379
[2] BALIUNAS et al. 1998 *Cool Stars X*, ASP Conf. Ser. **154** 153
[3] BALIUNAS et al. 1995 ApJ **438** 269

1982-2014: Solar Analogs and Twins

"The Sun Among the Stars" [1] [1978]

"Stars Resembling the Sun" [2] [1996]

"…we still have not been able to nominate a single star of the [109-star] sample for a 'perfect good solar twin.' "

Parameter	Sun	HR 6060
$\Delta T_{\rm eff}$ (K)	0	12 ± 30
$\Delta \log g$	0	0.05 ± 0.12
$L/L_\odot$	1.00	1.05 ± 0.02
[Fe/H]	0	0.05 ± 0.06
$(B-V)$	0.648	0.65
$(U-B)$	0.178	0.17
Spectral type	G2 V	G2 Va

[3]

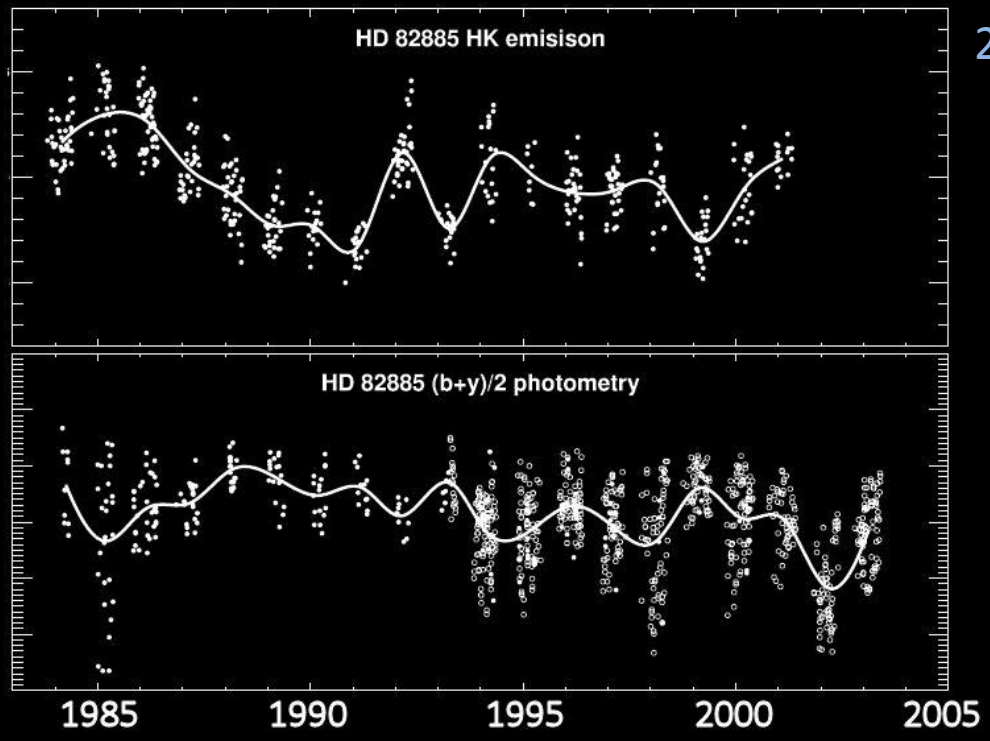
"Today, I hope that you all will agree with me that 18 Sco is currently the best match to the Sun." [4]

[1] HARDORP 1978 [2] CAYREL de STROBEL 1996 A&A Rev **7** 243

[3] DE MELLO & DA SILVA 1997 ApJL **482** L89

[4] CAYREL de STROBEL 1997 http://www.lowell.edu/users/jch/workshop/sa.html

1982-present : The Lowell/Fairborn APT program



ΔS

$\Delta(b+y)/2$

[2]




"…the phase of Ca II maximum flux corresponds to light minimum."[1]

[1] SKIFF & LOCKWOOD 1986 PASP **98** 338

[2] LOCKWOOD et al. 2007 ApJS **171** 260

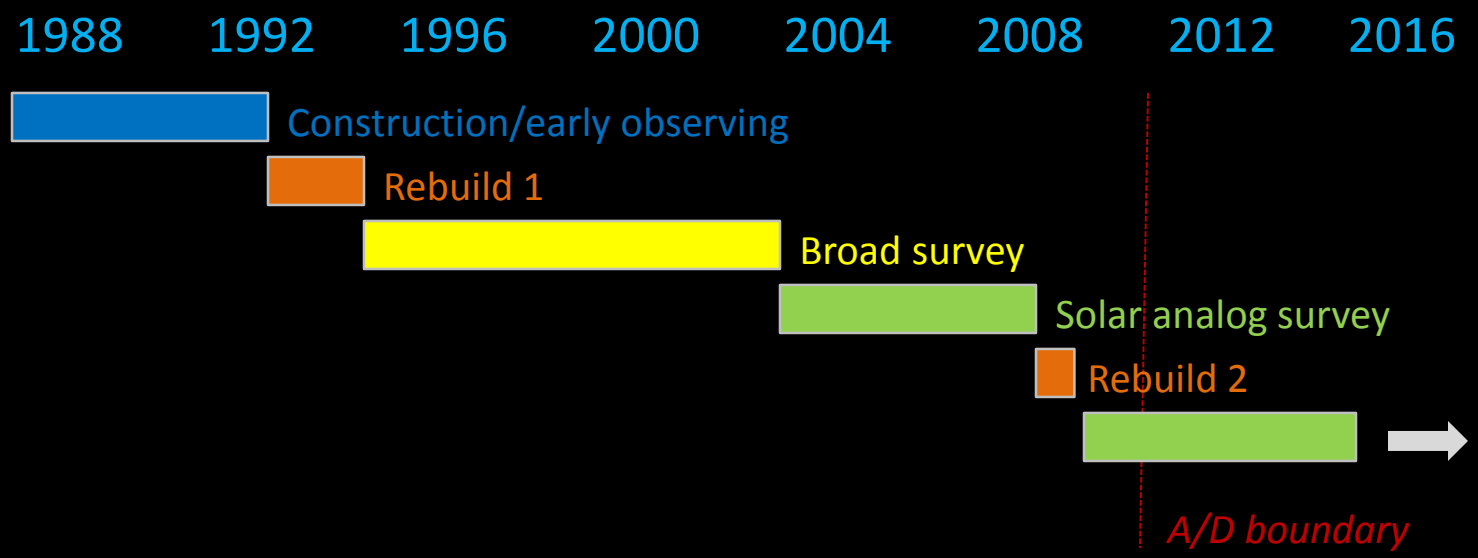
1982-present : The Lowell/Fairborn APT program

Lowell 0.5-m 1984-2000

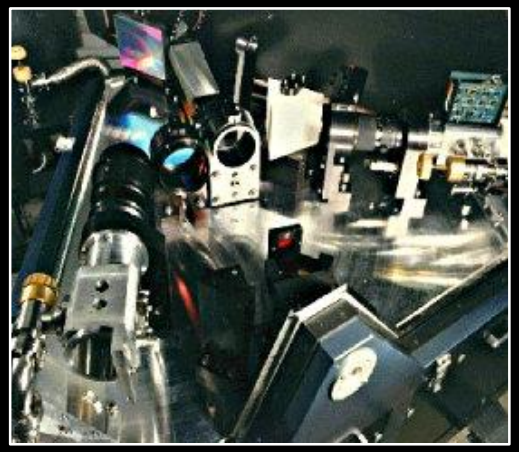
Fairborn (Tennessee State) automatic photoelectric telescopes[1] – 1996-present

[1] HENRY 1999 PASP **111** 845

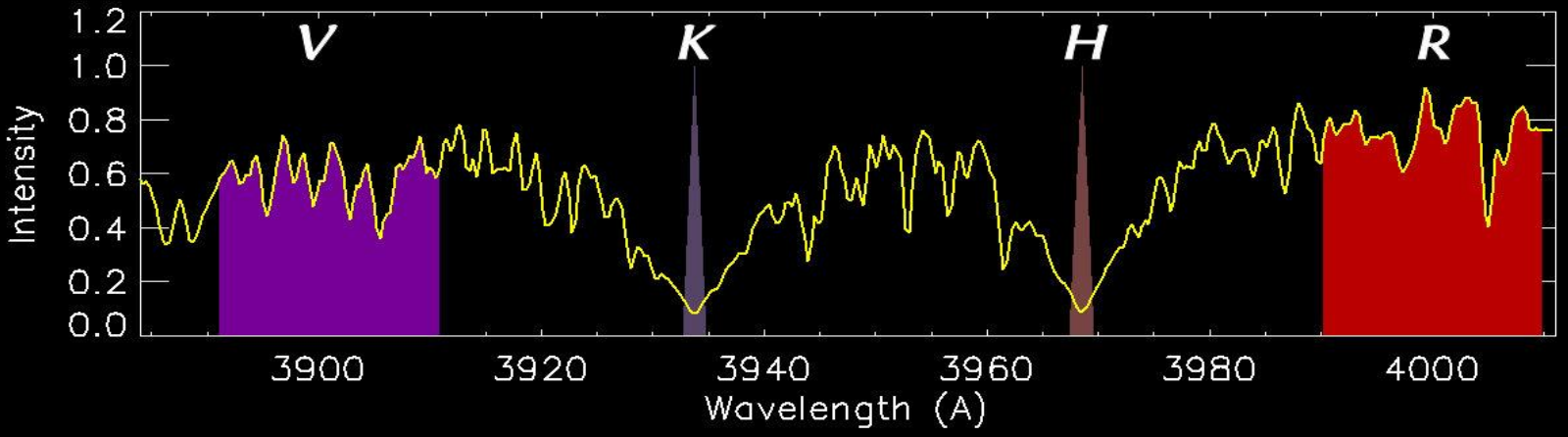
1994-present: The SSS Project at Lowell



1994-present: The SSS Project at Lowell



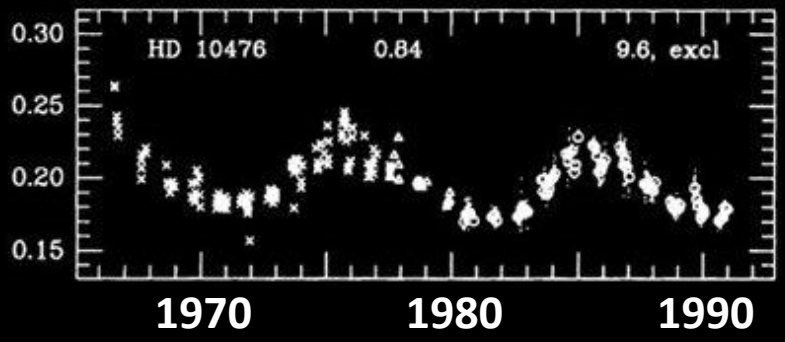
[1] HALL & LOCKWOOD 1995 ApJ **438** 404



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

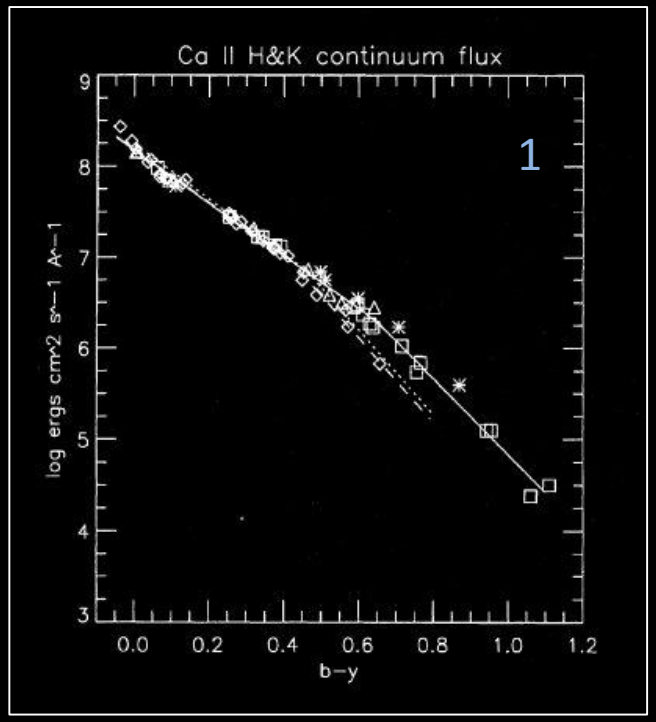
$S \rightarrow \log R'_{HK} \rightarrow \Delta F_{HK}$

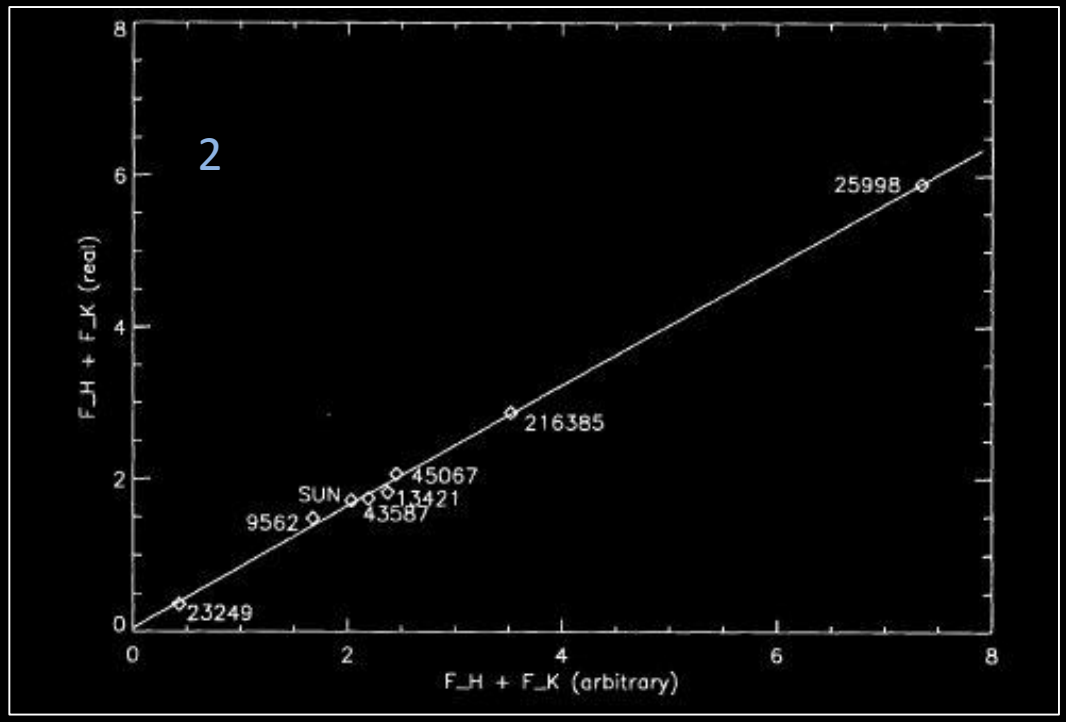
S



1 "An Excess of Art"
2 Sixty Years of Stargazing
3 Results & Case Studies
4 Prospects for the Future
5 "You were right"

1 – Connecting SSS to MWO



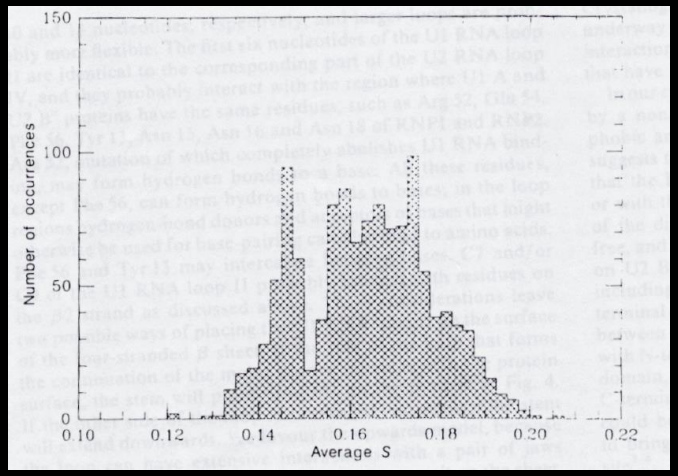


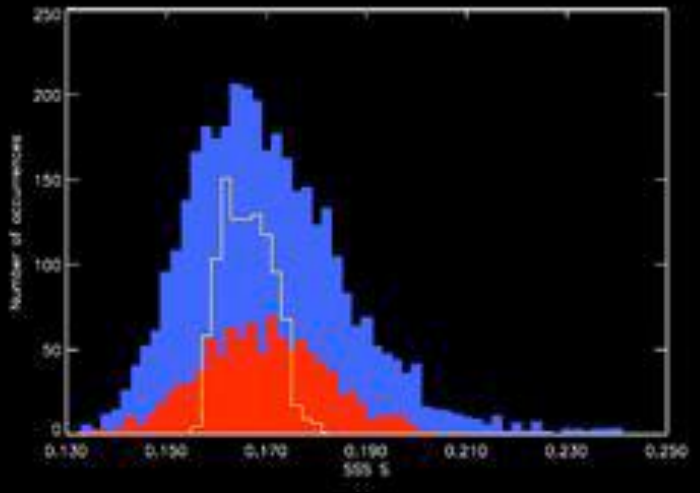
[1] HALL 1996 PASP **108** 313

[2] HALL & LOCKWOOD 1994 ApJ **438** 404

2 – Brightness Changes in Cycling and Non-Cycling Stars

1 2



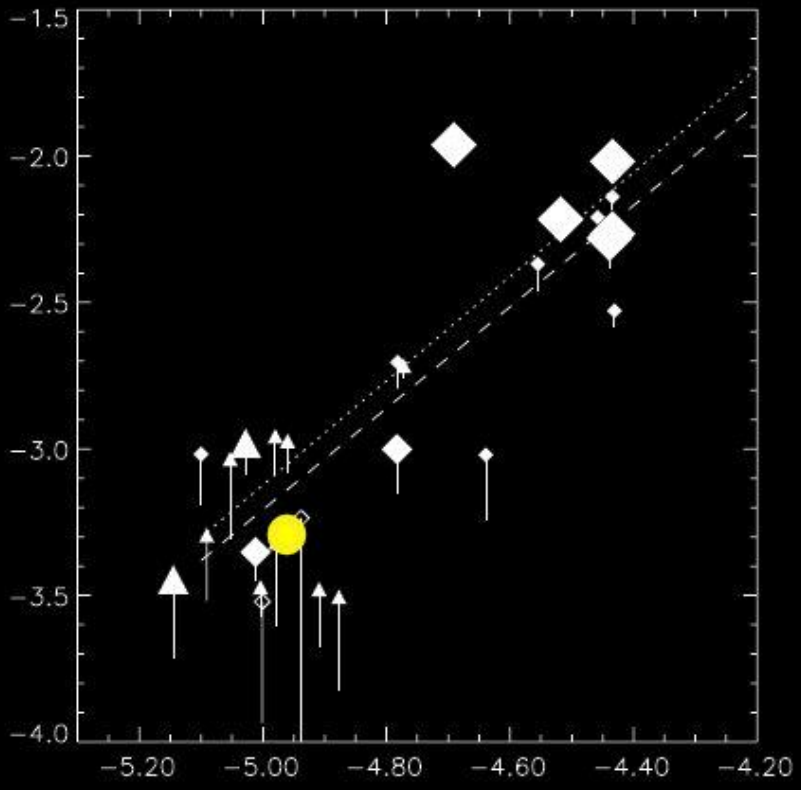


[1] BALIUNAS & JASTROW 1990 Nature **348** 520

[2] HALL & LOCKWOOD 2004 ApJ **614** 942

3 – Putting Solar Variability in Perspective

log rms *b-y*

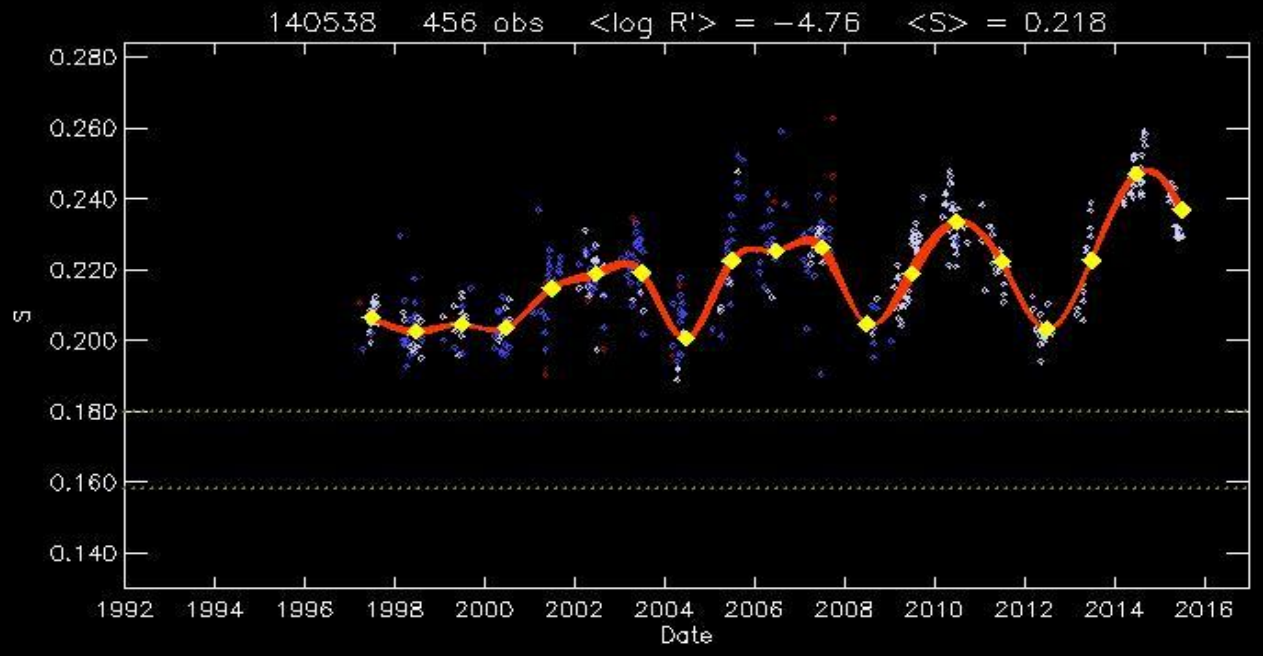


log R'_{HK}

[1] RADICK et al 1998 ApJS **118** 239
[2] LOCKWOOD et al 2007 ApJS **171** 260
[3] HALL et al 2009 AJ **138** 312

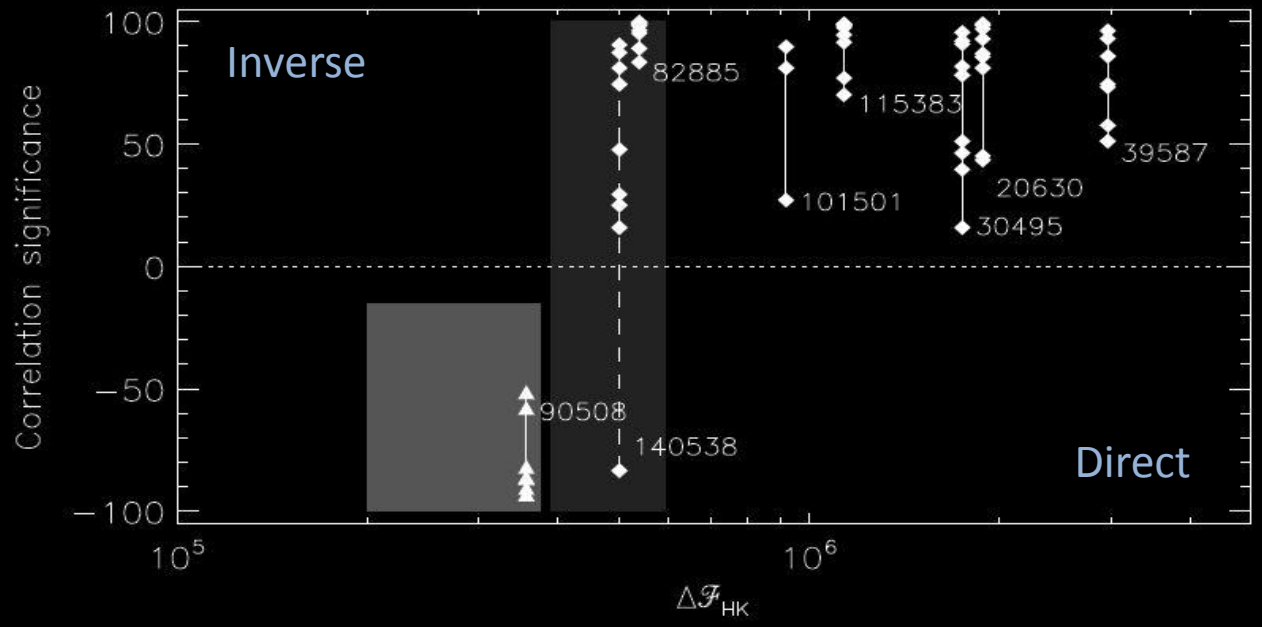
4 – Searching for Stellar Maunder Minima (Case Study 1)

Only one (semi-)convincing example of a FA-cycling transition in the SSS time series



4 – Searching for Stellar Maunder Minima (Case Study 1)

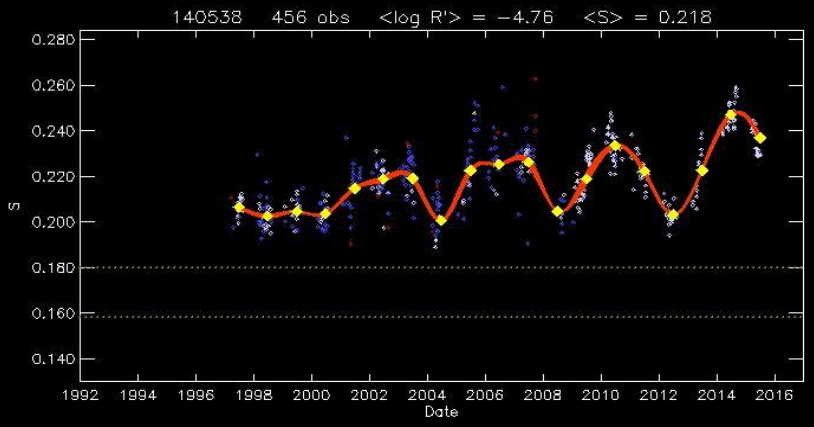
Also the only (semi-) convincing of a transition in the sense of the activity-brightness relationship for a singe star



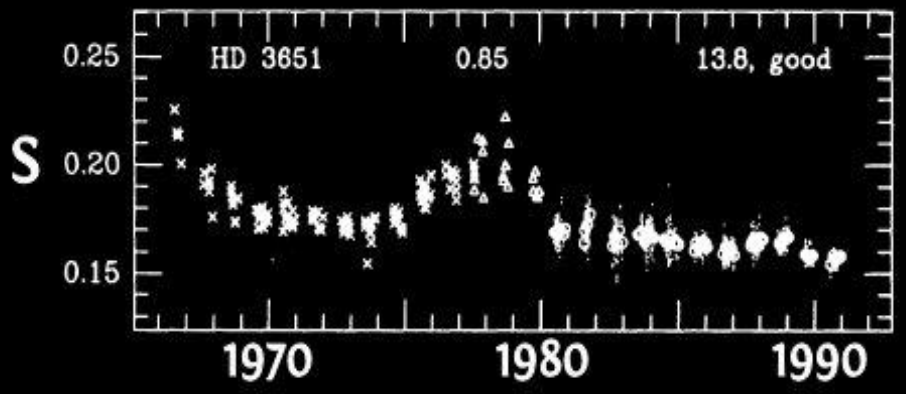
[1] HALL et al 2009 AJ 138 312

4 – Searching for Stellar Maunder Minima (Case Study 1)

"To date, there is no unambiguous identification of another star in a Maunder Minimum state." [1]



HD 140538

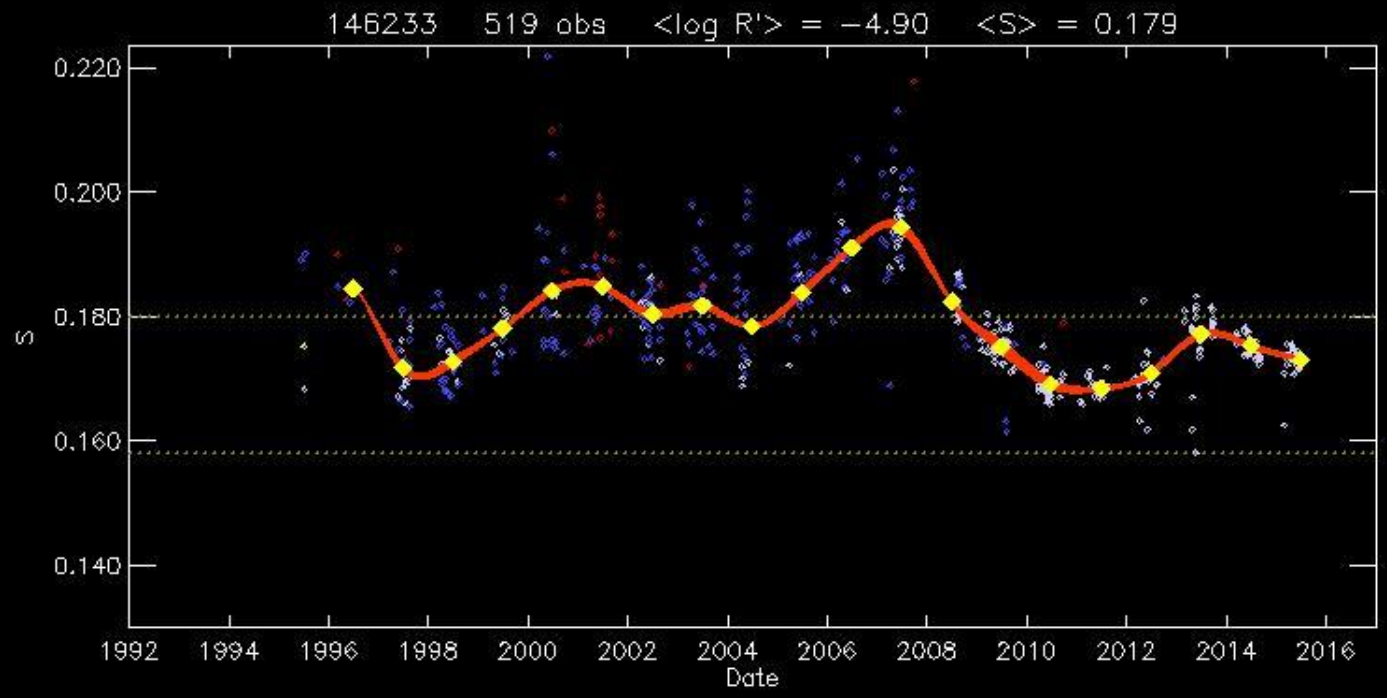


HD 3651

[1] WRIGHT 2004 AJ **128** 1273

Case Study 2: The solar twin 18 Scorpii

Chromospheric activity is solar-like[1] but 22.7d rotation period[2] and ~7-year activity cycle are shorter. Excellent photometric twin.



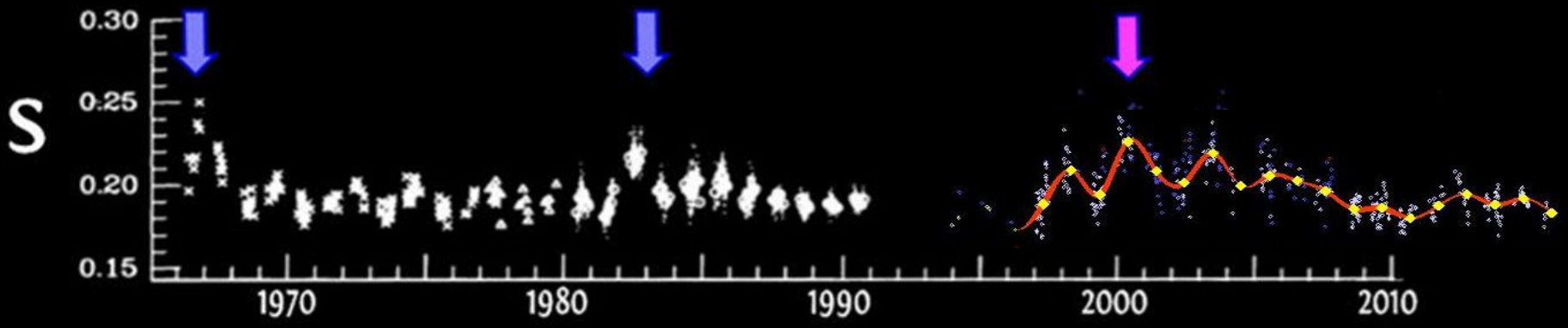
[1] HALL, HENRY, & LOCKWOOD 2007 AJ **133** 2206

[2] PETIT et al 2008 MNRAS **388** 80

Case Study 3: HD 190406 (15 Sge)

HD 190406 is the one solar analog for which the SSS series clearly recovers the multiply periodic character of the MWO series over ~50 yr

Baliunas et al. 1995 16.9 yr + 2.6 yr



1 "An Excess of Art"
2 Sixty Years of Stargazing
3 Case Studies and Current Efforts
4 **Prospects for the Future**
5 "You were right"

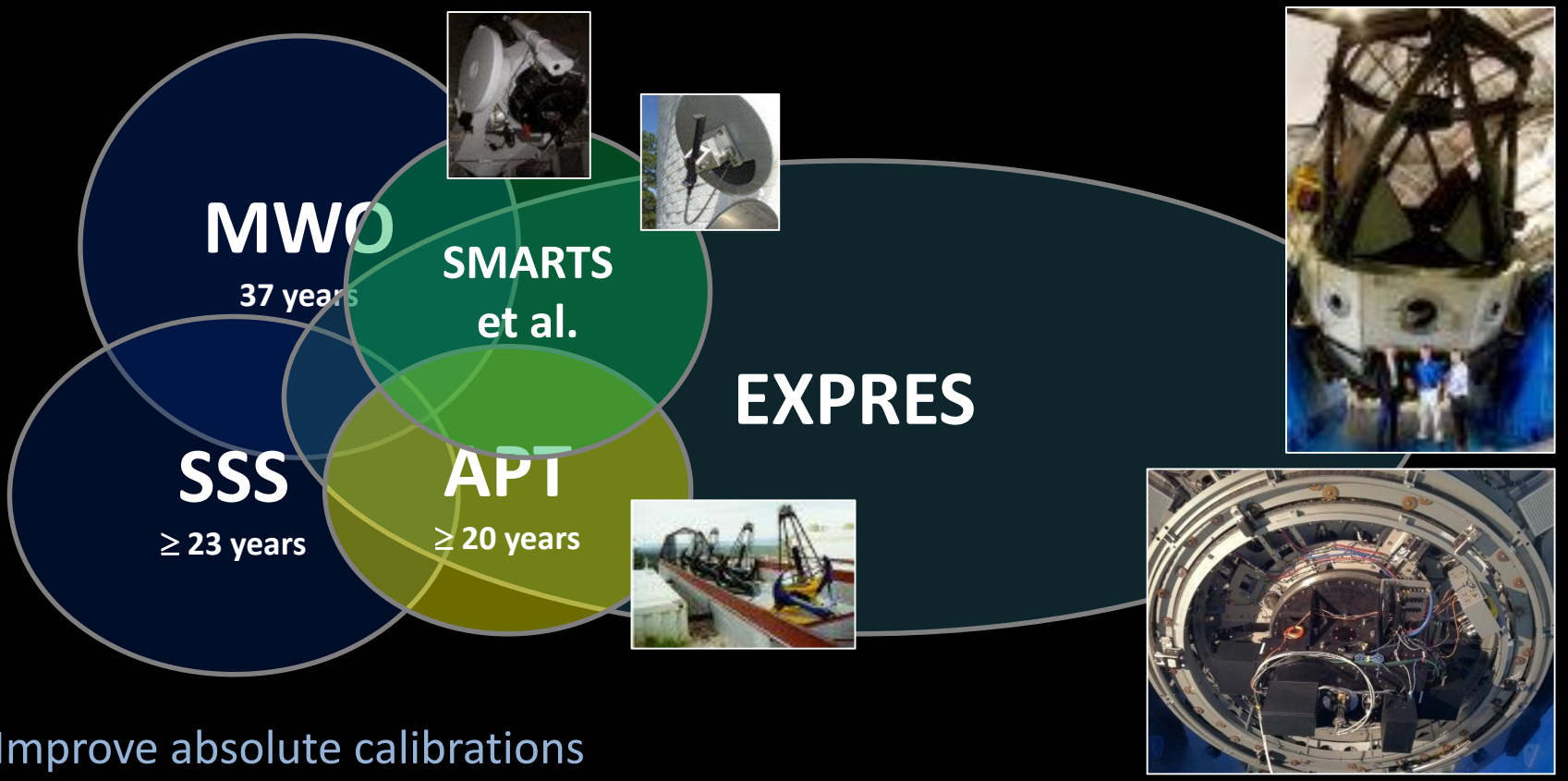
Create community resource

- combine extant multi-decadal time series (MWO + SSS + …)
- reconcile calibrations and systematics
- make available via public database

Expand synoptic observations

- via “boring” HK studies
- via multi-proxy programs to examine the nature of stellar MM more efficiently
- via expansion of the sample to fainter solar twins

From 1.1 meters to 4.3 meters



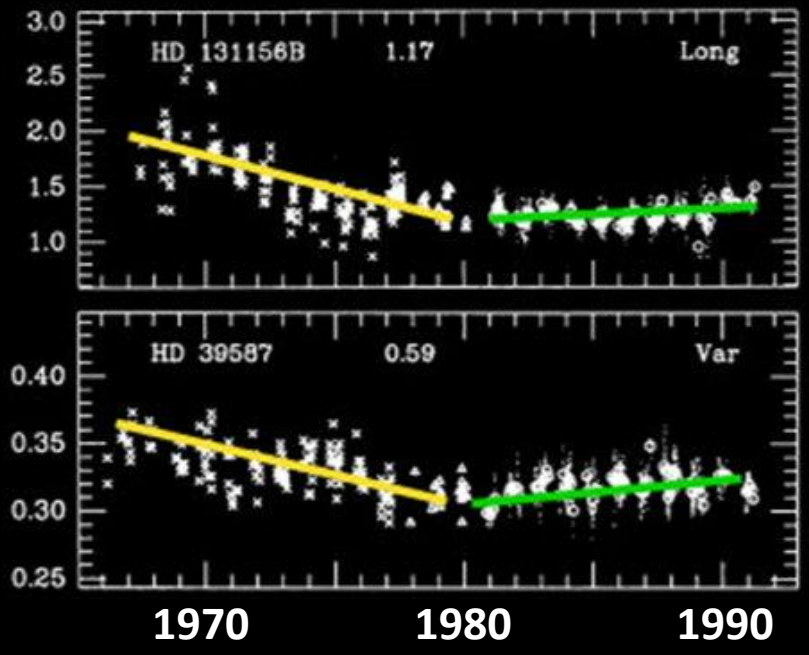
Improve absolute calibrations

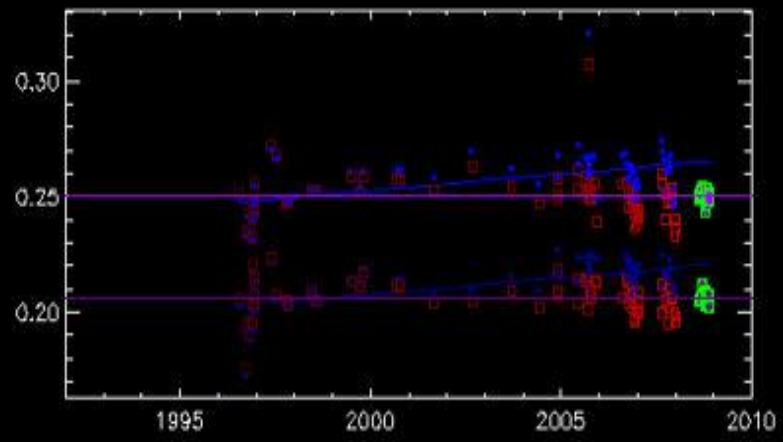
Use overlapping observations of MWO/SSS stars to bootstrap interpretation of larger sample

1 “An Excess of Art”
2 Sixty Years of Stargazing
3 Case Studies and Current Efforts
4 Prospects for the Future
5 “You were right”

Reconciling extant data to each other, and to theory

Resolve challenges in the MWO and SSS data, which epitomize "the good, the bad, and the ugly" [1]





[1] MASSEY & JACOBY 1992 ASP Conf. Ser. **23** 240

Notes from the field

Donahue 1997

Baliunas 2004

Soon 2015

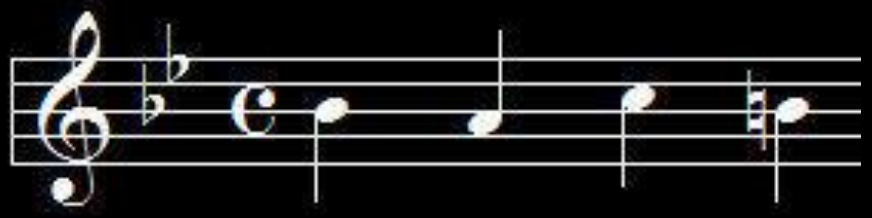
Garrison 1984:

"Hardorp set out, with good intentions, to find a solar analog… [but] he has muddied the waters considerably." [1]

"Bob, you were right." [2]

[1] GARRISON 1984 IAU Symp. 111, ed. D. S. Hayes, p. 25

[2] GARRISON 1997 Solar Analogs Workshop, Lowell Obs. http://www.lowell.edu/users/jch/workshop/sa.html



B A C H