The evolution of chromospheric activity is L-shaped

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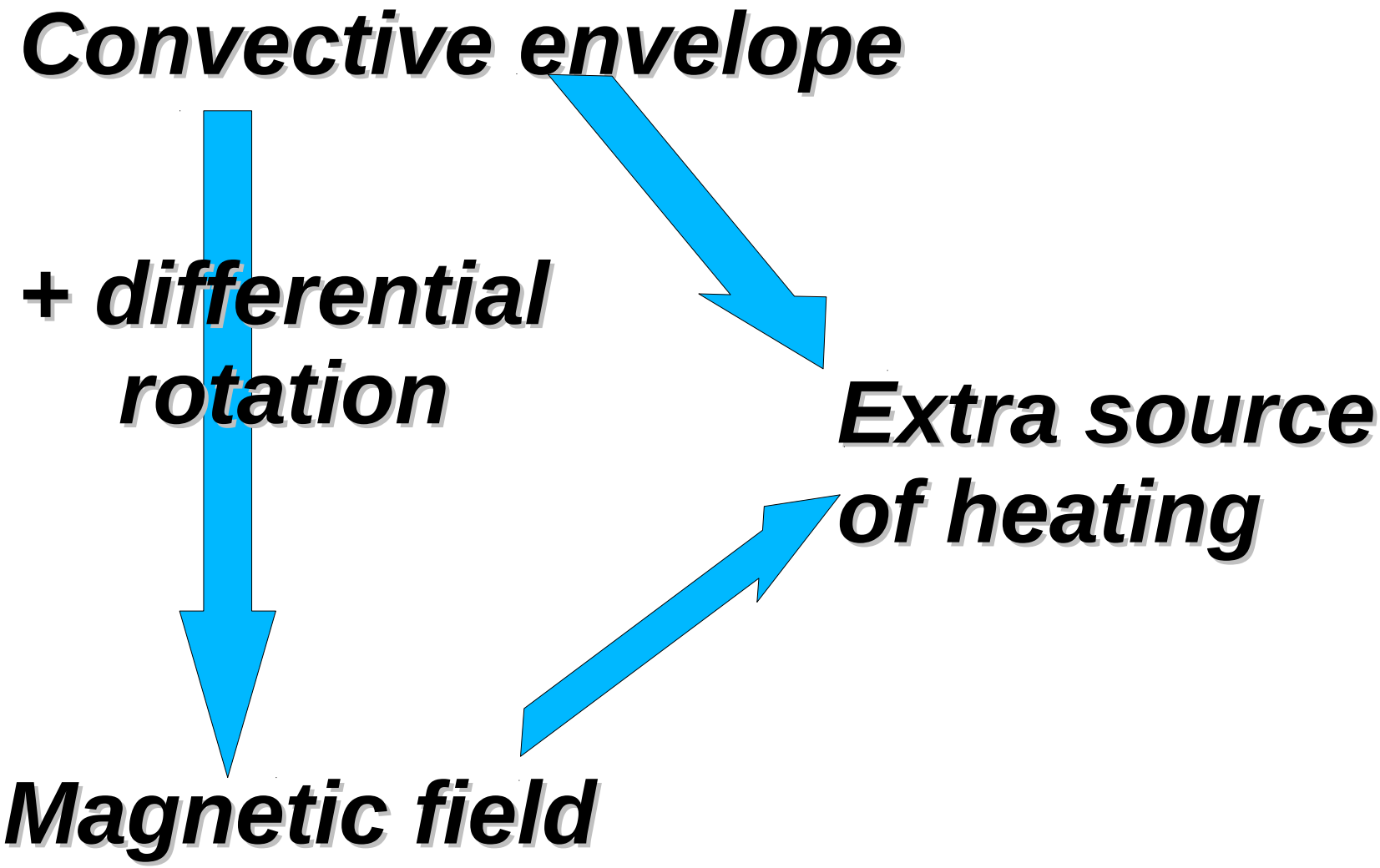
ENAA XXIII

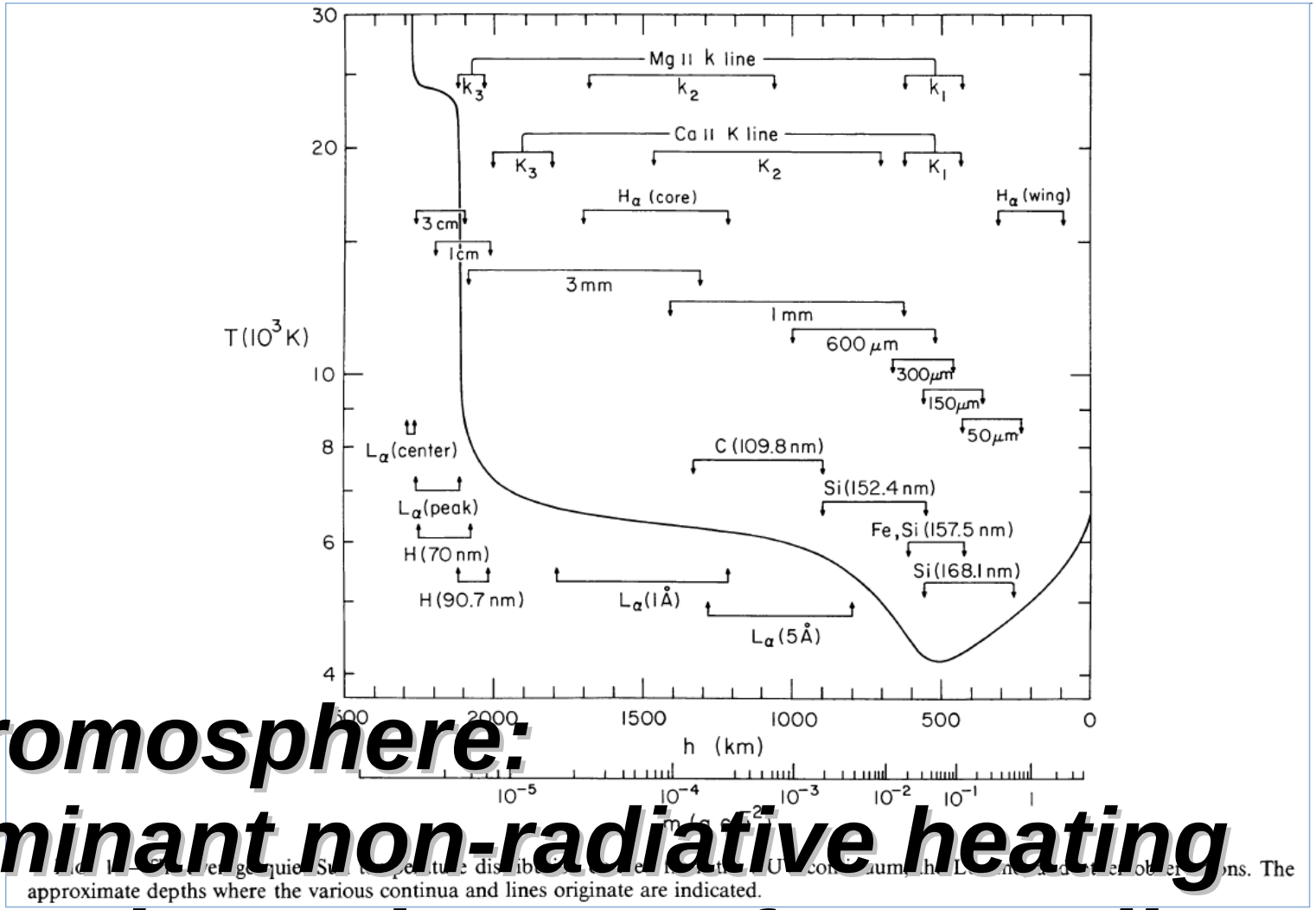
Topics

- Introduction on chromospheric activity
- The S-index and log R'_{HK}
- Evolution of chromospheric activity with time
- Evolution of rotation
- Open issues

The solar dynamo



What a chromosphere is



approximate depths where the various continua and lines originate are indicated.

Chromosphere:
Dominant non-radiative heating
Loss through core of strong lines

Summary of lesson 1: what a chromosphere is

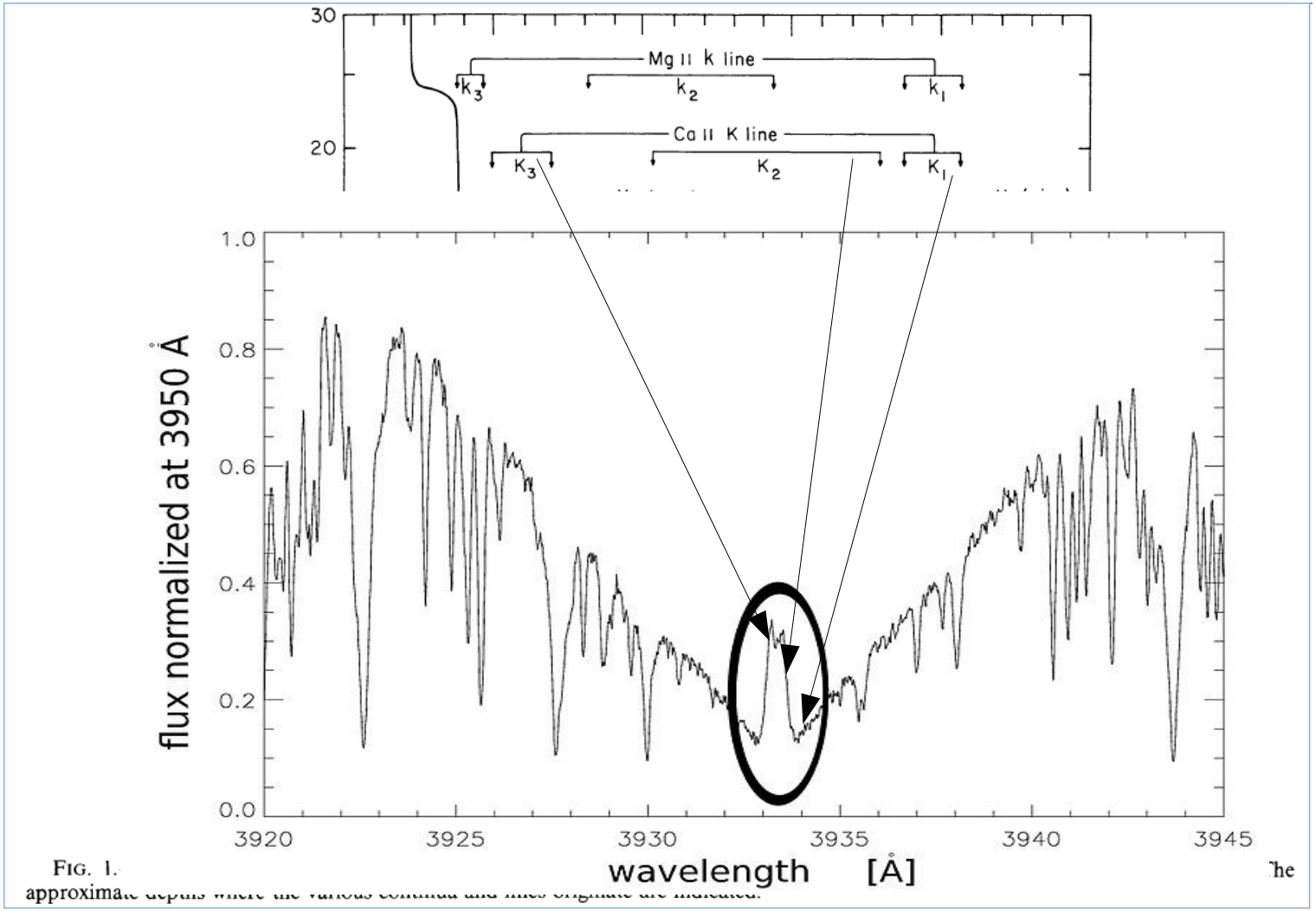
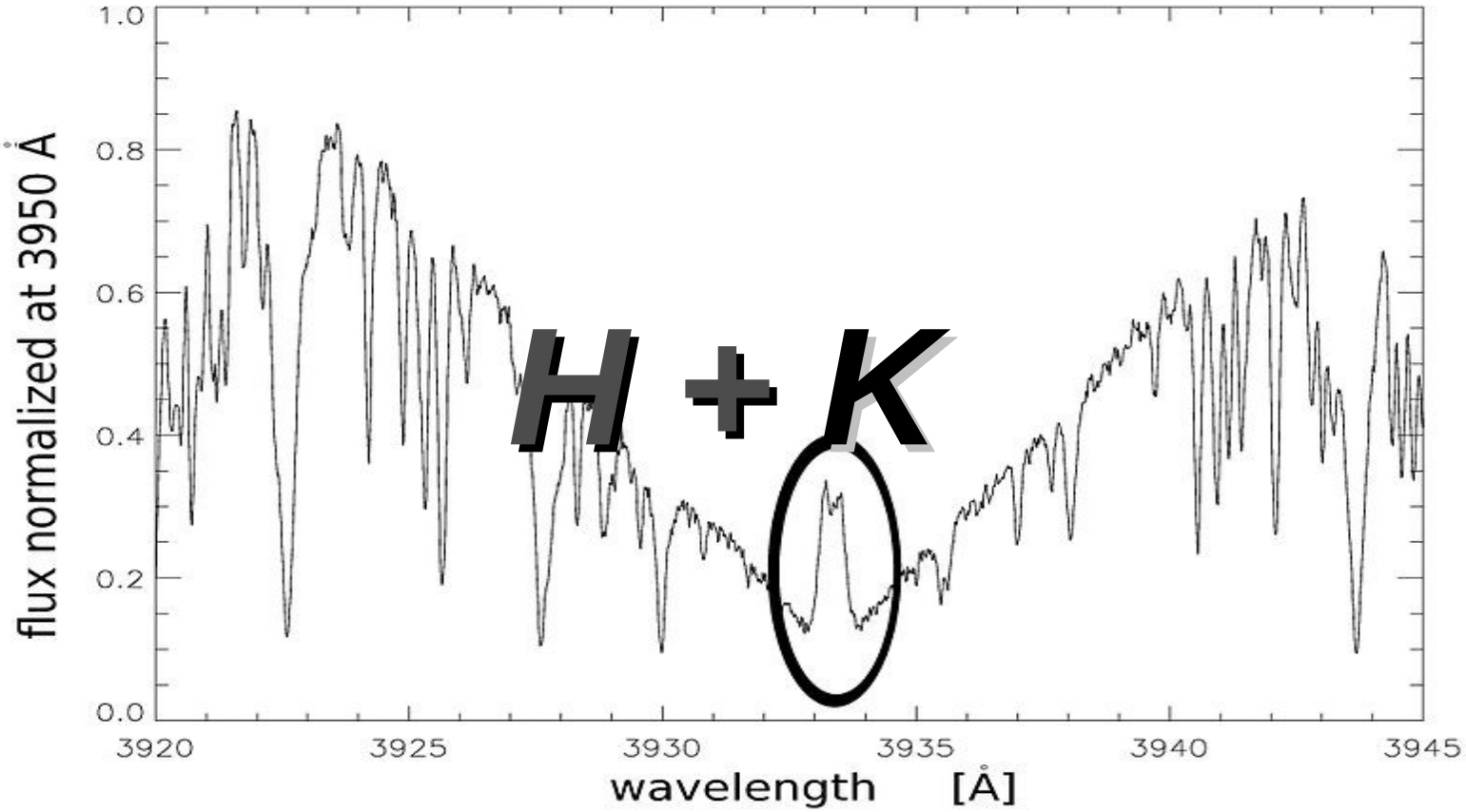
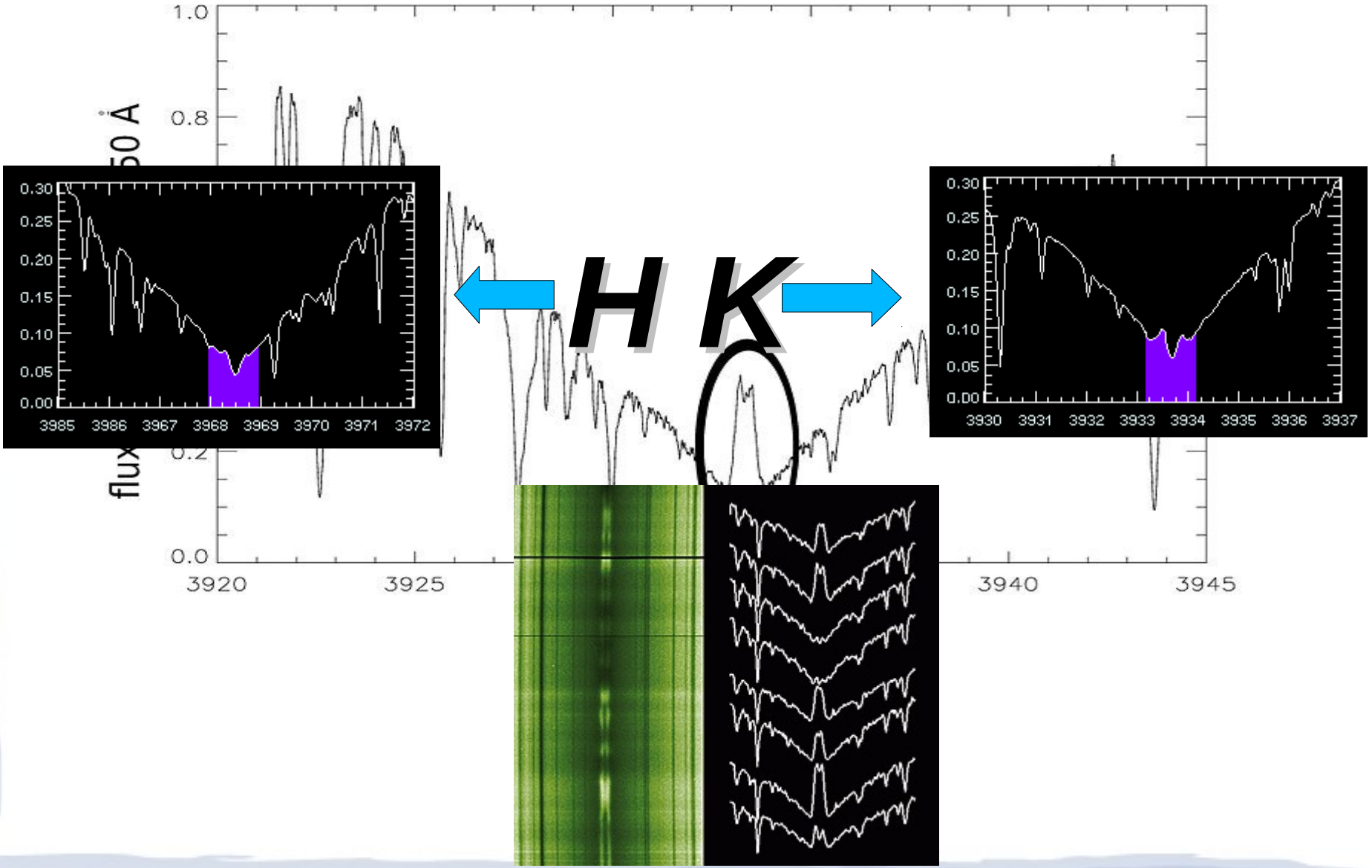


FIG. 1. approximate depths where the various continua and lines originate are indicated. The

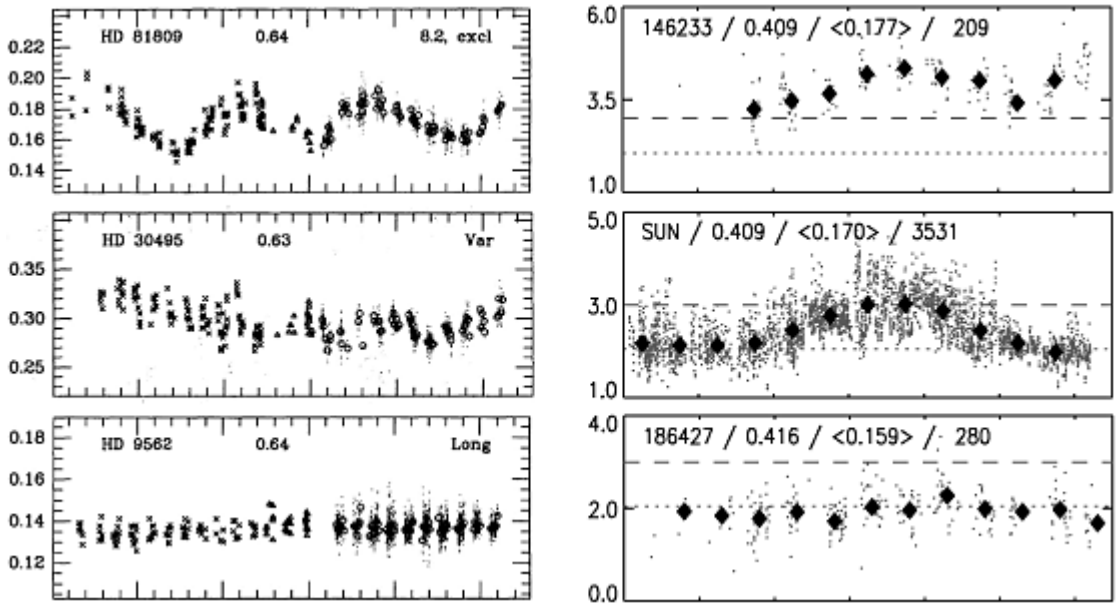
The S-index


flux normalized at 3950 Å
1.0
0.8
0.6
0.4
0.2
0.0
3920
3925
3930
3935
3940
3945
wavelength [Å]
H + K

The S-index


H
K
flux
1.0
0.8
0.2
0.0
3920
3925
3940
3945
0.30
0.25
0.20
0.15
0.10
0.05
0.00
3985 3986 3967 3968 3969 3970 3971 3972
3930 3931 3932 3933 3934 3935 3936 3937

Baliunas et al 1998:
~60% periodic, cyclic variations,
~25% irregular or aperiodic variability
~15% flat activity



Baliunas et al 1995

Skumanich law (1972)

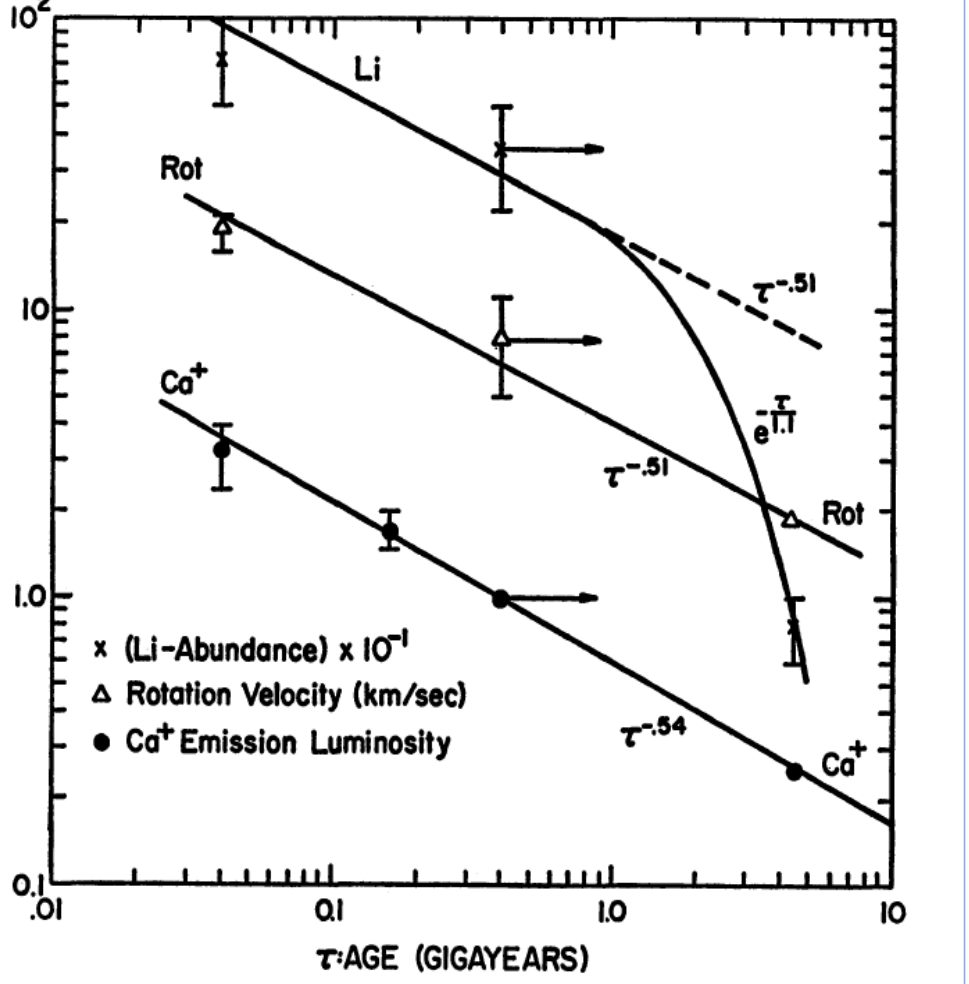


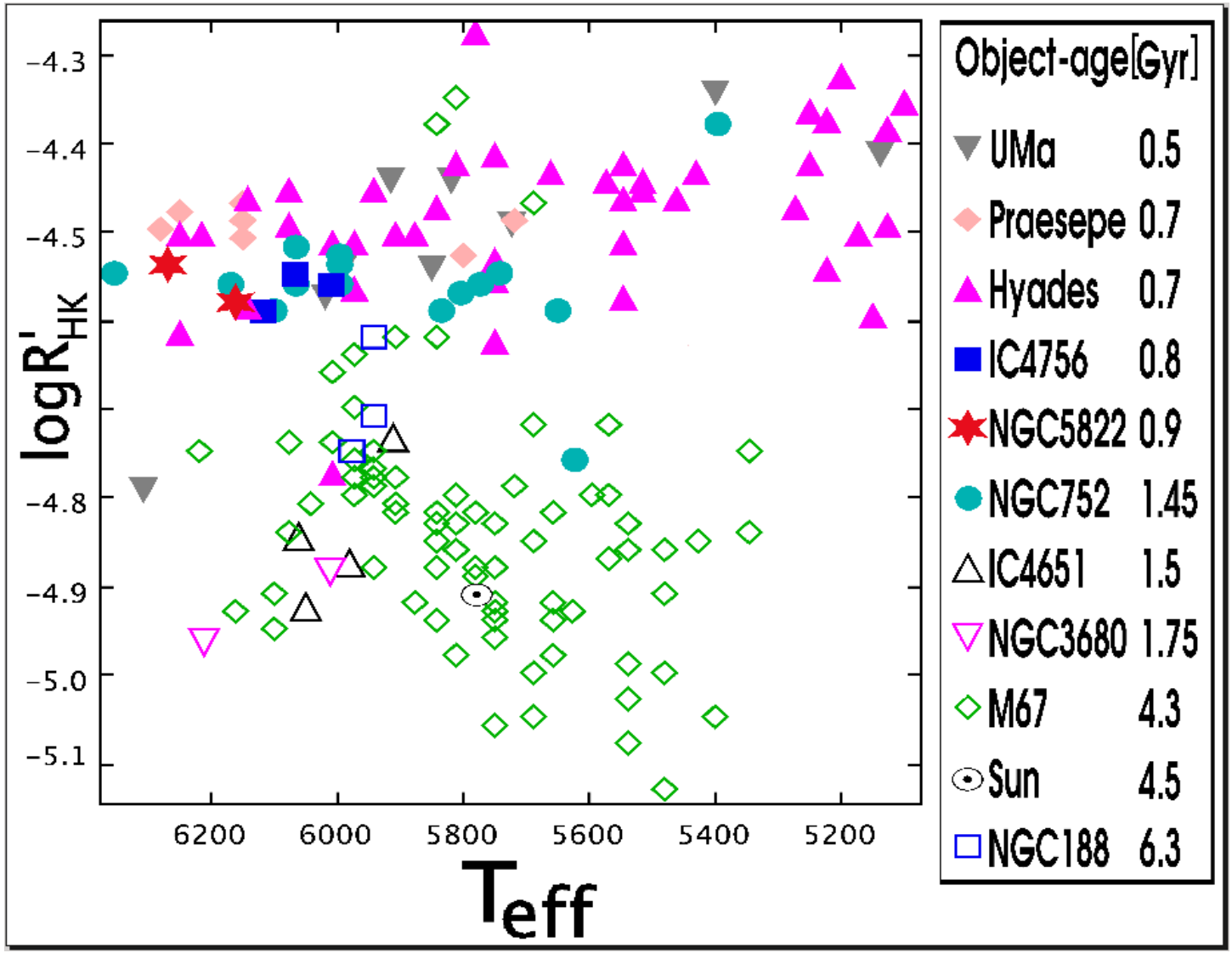
FIG. 1.—Ca^+ emission, rotation, and lithium abundance versus stellar age

The S-index measurements in the literature

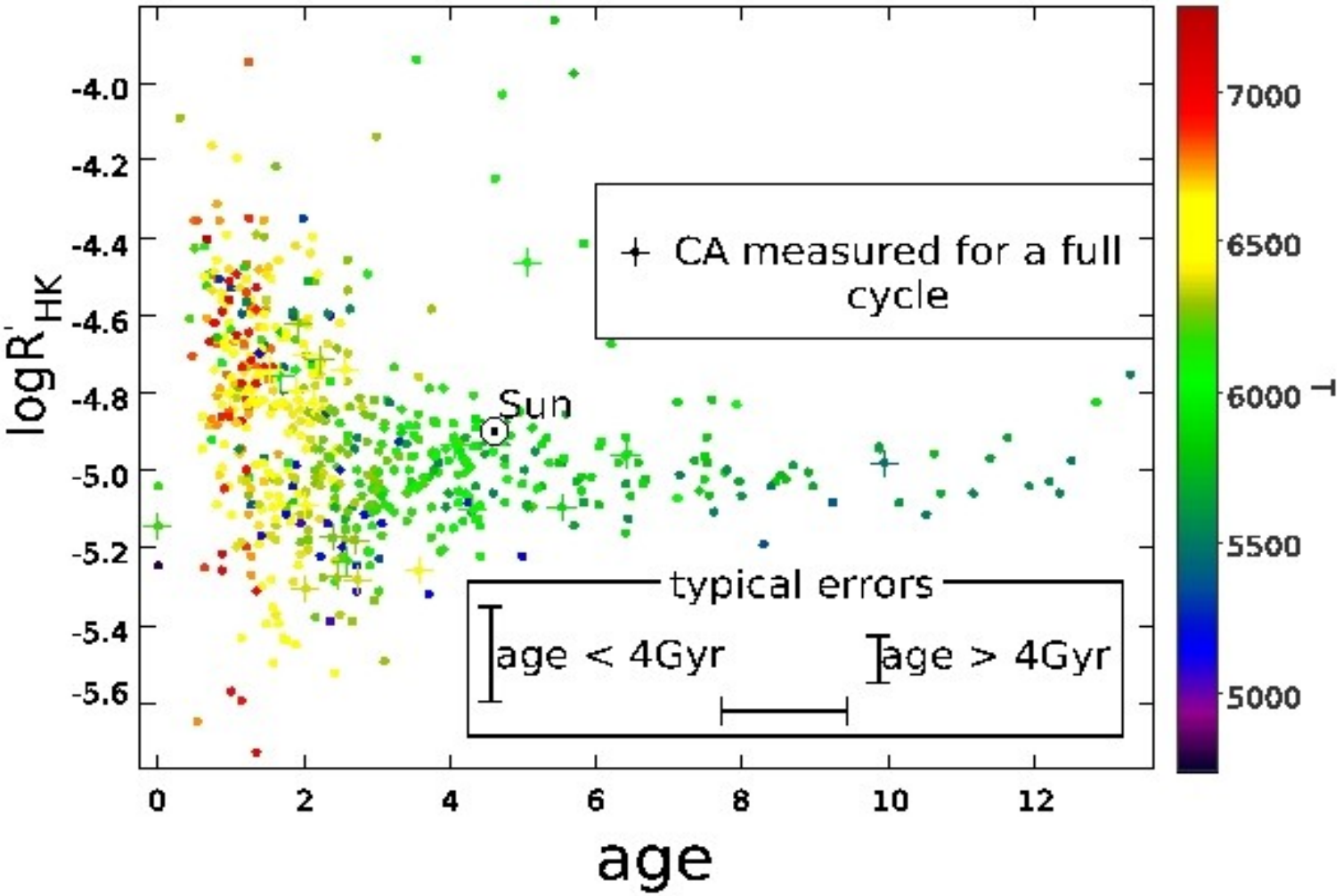
- The HK project started in the mid 60s in the Mount Wilson Observatory by Olin C. Wilson
- Lowell Observatory (Solar Stellar Spectrograph)
- California Planet Search
- Carnegie Planet Search

Arriagada (2011); Jenkins et al. (2011); Baliunas et al. (1995); Knutson et al. (2010); Cincunegui et al. (2007); Lockwood et al. (2007); Duncan et al. (1991); López-Santiago et al. (2010); Gray et al. (2003); Schrõder et al. (2009); Gray et al. (2006); Tinney et al. (2002); Hall et al. (2007); White et al. (2007); Henry et al. (1996); Wright et al. (2004); Isaacson and Fischer (2010)

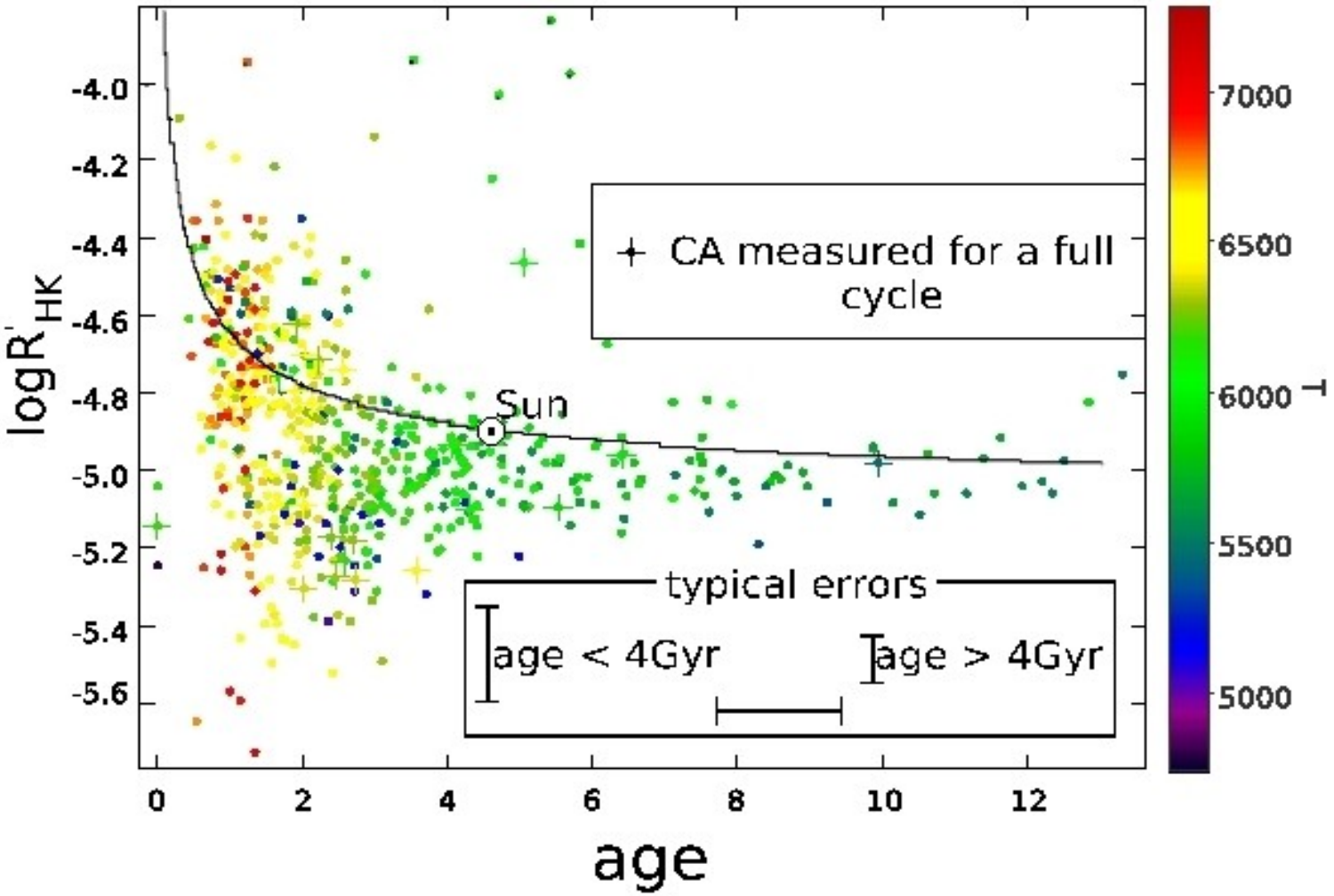
CA evolution



CA evolution



CA evolution



Mamajek & Hillenbrand 2008

TABLE 7
$\log R'_{HK}$ Data for Ancillary Samples

Cluster Name (1)	Age (Myr) (2)	Age References (3)	Original $\log R'_{HK}$ (4)	Corrected $\log R'_{HK}$ (5)	$\log R'_{HK}$ References (6)
M34	200	1	−4.4:	...	7
Coma Ber	600	2	−4.51	−4.43	8
NGC 752	2000	3	−4.70	−4.70	8
M67	4000	4, 5	−4.82	−4.86	8
NGC 188	6900	4, 5	−4.98	−5.08	8
Old field	8000	6	−4.99	...	6

Notes.—Col. (1): Name of group. Col. (2): Age. Col. (3): Age reference. Col. (4): Originally quoted mean $\log R'_{HK}$ value. Col. (5): Corrected mean $\log R'_{HK}$ value (only relevant for reference 8). Col. (6): Activity references.
References.—(1) Jones et al. 1997; (2) King & Schuler 2005; (3) Dinescu et al. 1995; (4) Sarajedini et al. 1999; (5) VandenBerg & Stetson 2004; (6) this study (§ 2.4.6); (7) visual inspection of Fig. 1 of King et al. 2003; (8) data from Barry 1988, corrected following Soderblom et al. 1991.

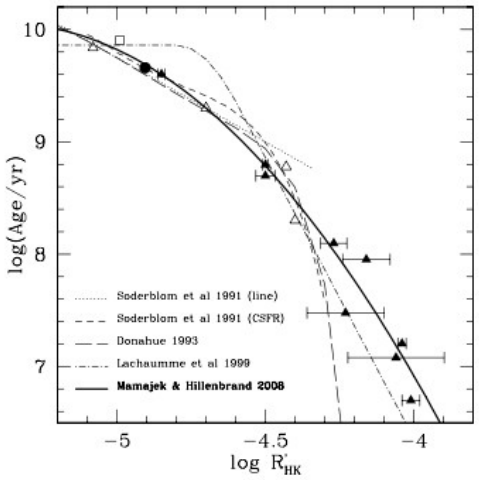
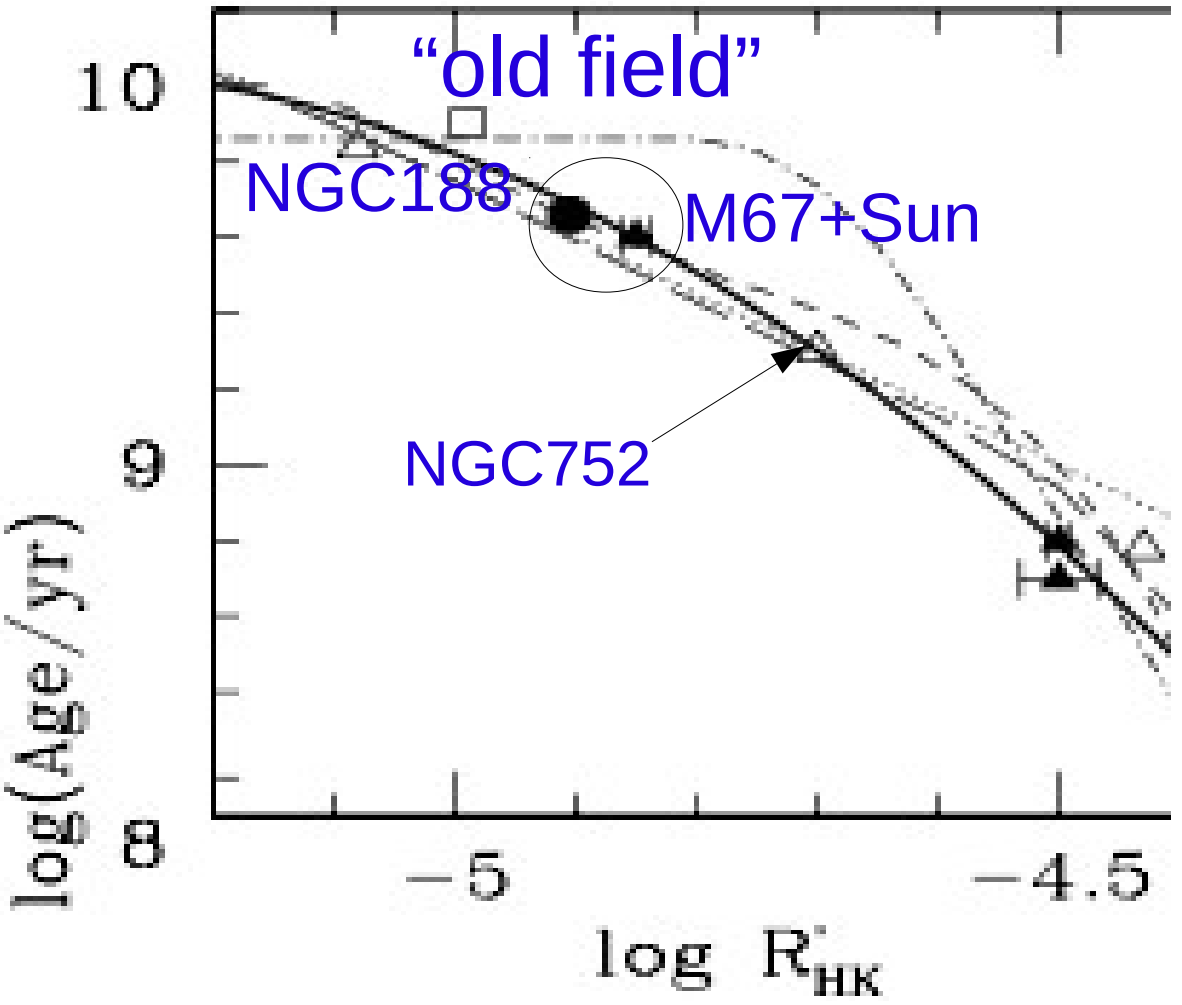


TABLE 6
Cluster $\log R'_{HK}$ Values

Group Name (1)	Age (Myr) (2)	References (3)	$\log R'_{HK}$ Median (4)	68% CL (5)	N (6)	Activity-Color Slope m (7)	$\overline{\log R'_{HK}}\ (B-V)_\odot$ (8)
USco	5	1, 2, 3	−4.05 ± 0.03	0.13	9	−0.73 ± 0.62	−4.01
β Pic	12	4, 5	−4.03 ± 0.13	0.23	6	1.40 ± 0.30	−4.06
UCL+LCC	16	6, 7	−4.04 ± 0.01	0.07	10	−0.37 ± 0.27	−4.04
Tuc-Hor	30	6, 7, 8	−4.16 ± 0.13	0.16	8	3.02 ± 0.45	−4.23
α Per	85	9, 10, 11	−4.16 ± 0.08	0.27	13	2.04 ± 1.52	−4.16
Pleiades	130	9, 11, 12	−4.33 ± 0.04	0.24	56	0.75 ± 0.24	−4.27
UMa	500	13	−4.48 ± 0.03	0.09	17	0.80 ± 0.27	−4.50
Hyades	625	11, 14	−4.47 ± 0.01	0.09	87	0.14 ± 0.13	−4.50
M67	4000	15, 16	−4.84 ± 0.01	0.11	76	−1.03 ± 0.23	−4.85

Notes.—Col. (1): Name of group. Col. (2): Age. Col. (3): Age and membership references. Col. (4): $\log R'_{HK}$ median and uncertainty (Gott et al. 2001). Col. (5): 68% confidence intervals on $\log R'_{HK}$. Col. (6): Number of data points per bin. Col. (7): OLS bisector slope $m = \Delta \log R'_{HK}/\Delta B - V$ and uncertainty. Col. (8): Mean $\log R'_{HK}$ interpolated at solar $(B-V)_\odot$. OLS$(Y|X)$ slopes and uncertainties were calculated using 10^4 jackknife sampling simulations, except for β Pic and Tuc-Hor, where the slope was analytically calculated, due to their small sample size. Estimation of the solar $\log R'_{HK}$ value is discussed in § 1.
References.—(1) Preibisch et al. 2002; (2) Preibisch & Zinnecker 1999; (3) Walter et al. 1994; (4) Ortega et al. 2002; (5) Zuckerman & Song 2004; (6) Mamajek et al. 2002; (7) de Zeeuw et al. 1999; (8) Mamajek et al. 2004; (9) Barrado y Navascués et al. 2004; (10) Makarov 2006; (11) this work (§ 2.2); (12) Duncan et al. 1991; (13) King et al. 2003; (14) Perryman et al. 1998; (15) VandenBerg & Stetson 2004; (16) Giampapa et al. 2006, selected from Girard et al. 1989.


“old field”
NGC188
M67+Sun
NGC752
10
9
8
−5
−4.5
log(Age/yr)
log R'НК

Rotation evolution: gyrochronology (Barnes 2010)

The model is calibrated on the Sun with input from open-cluster rotation period observations

$$\frac{dP}{dt} = \left\{ \frac{k_I P}{\tau} + \frac{\tau}{k_C P} \right\}^{-1}$$

τ: convective turnover timescale

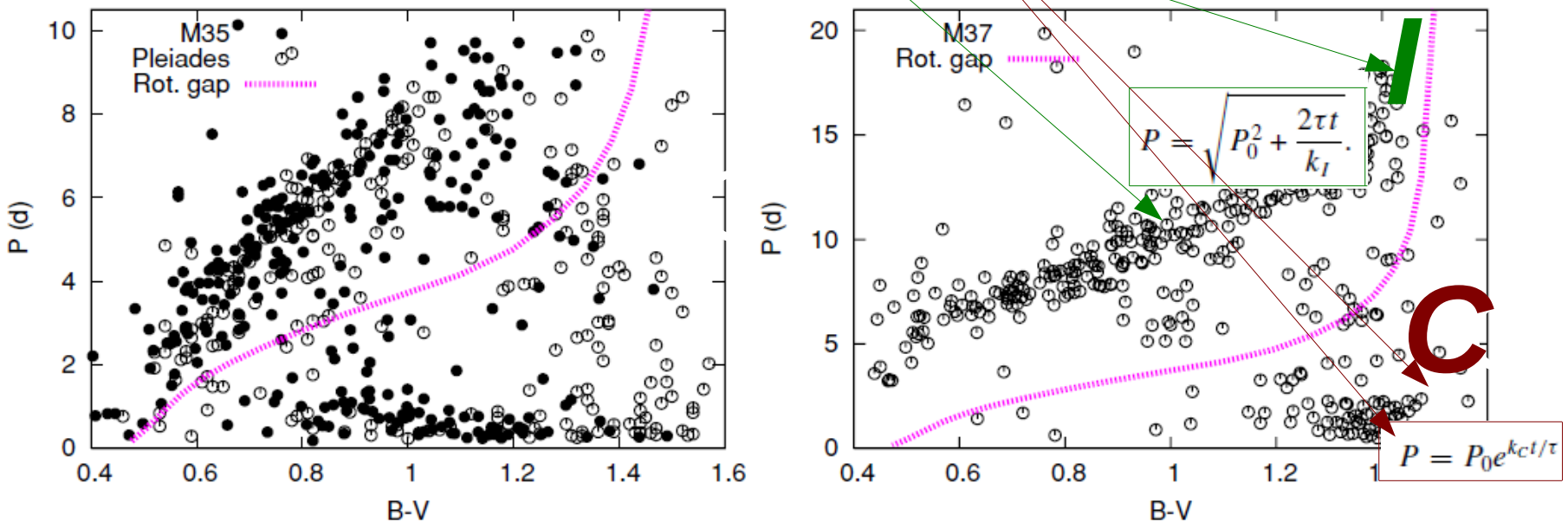
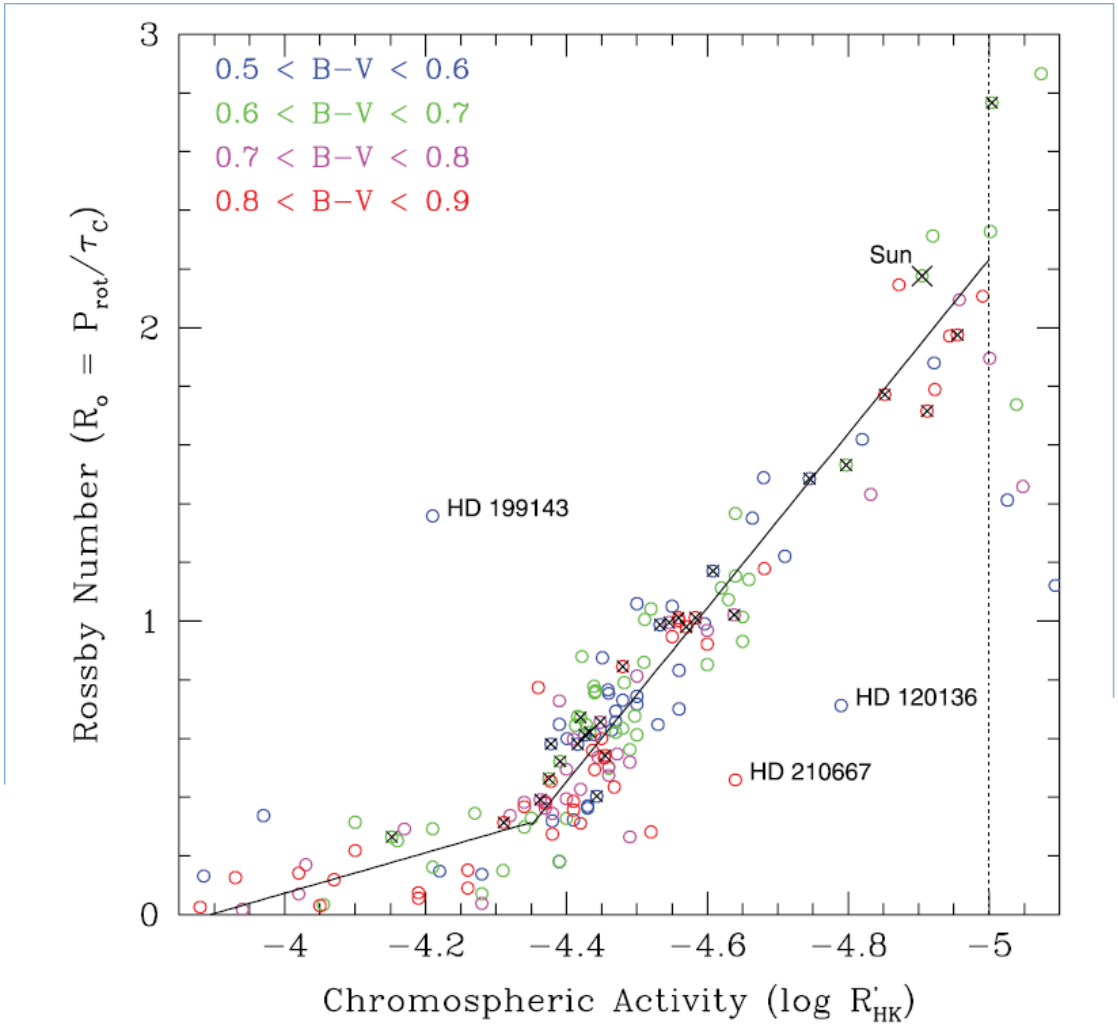


Figure 9. A paucity of stars is expected and observed at the C/I boundary (rotational gap) region (dotted pink lines) because dP/dt is at a maximum here. The regions to the lower right and upper left are the provinces of the C-type and I-type rotators, respectively, because dP/dt is much lower there. Left: the M35 (solid symbols; Meibom et al. 2009) and Pleiades (unfilled symbols; Hartman et al. 2010) rotation period observations are displayed in relation to the calculated position of the gap. Right: the M37 observations (Hartman et al. 2009) are similarly displayed. (Note the twofold compression of the period axis in this panel.)

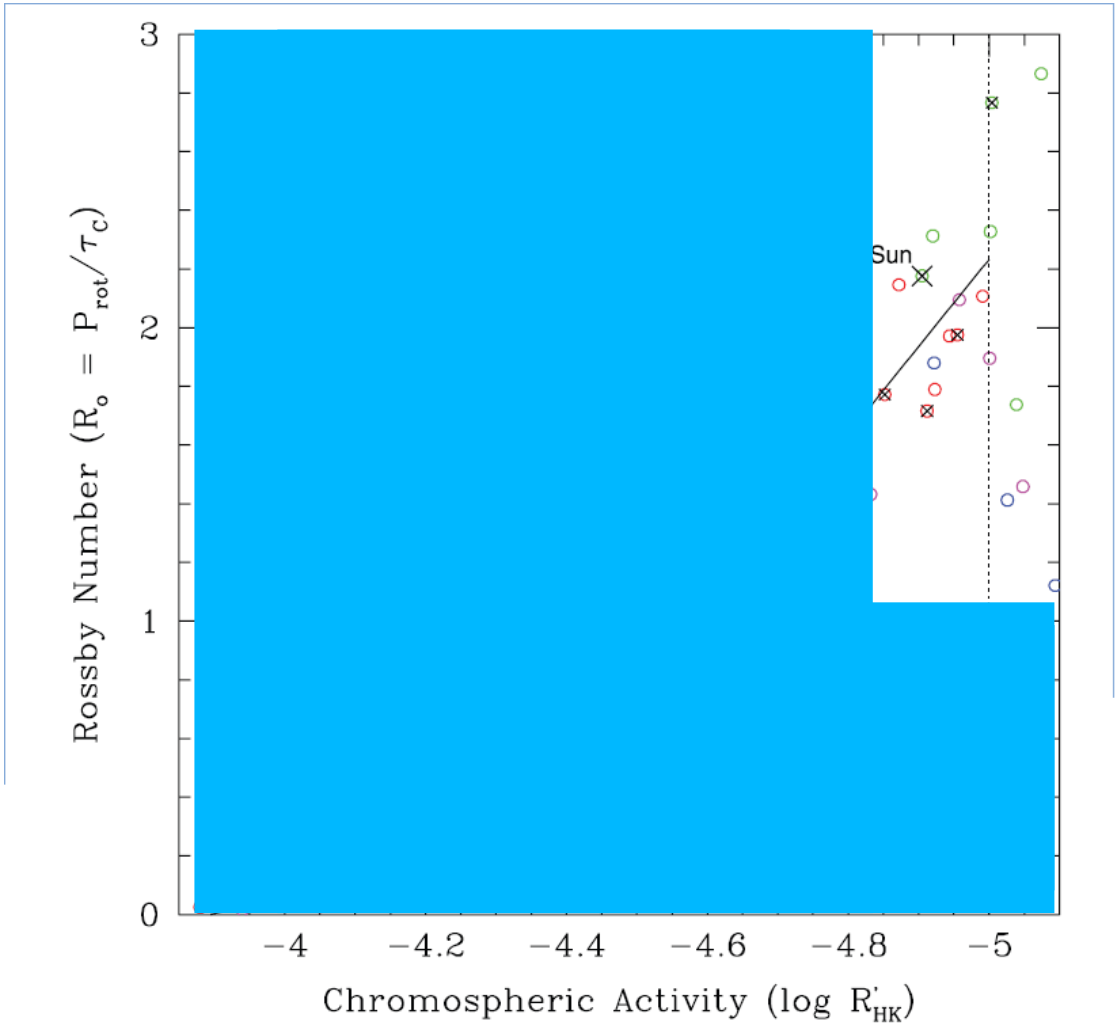
M35+Pleiades(~150 Myr) M37 (~400 Myr)

gyrochronology is a phenomenological description of rotation evolution that can be approximated at old ages by the Skumanich law. However, there are no direct rotation period measurements for clusters older than the Hyades (3 old clusters in the Kepler field, Meiobom).

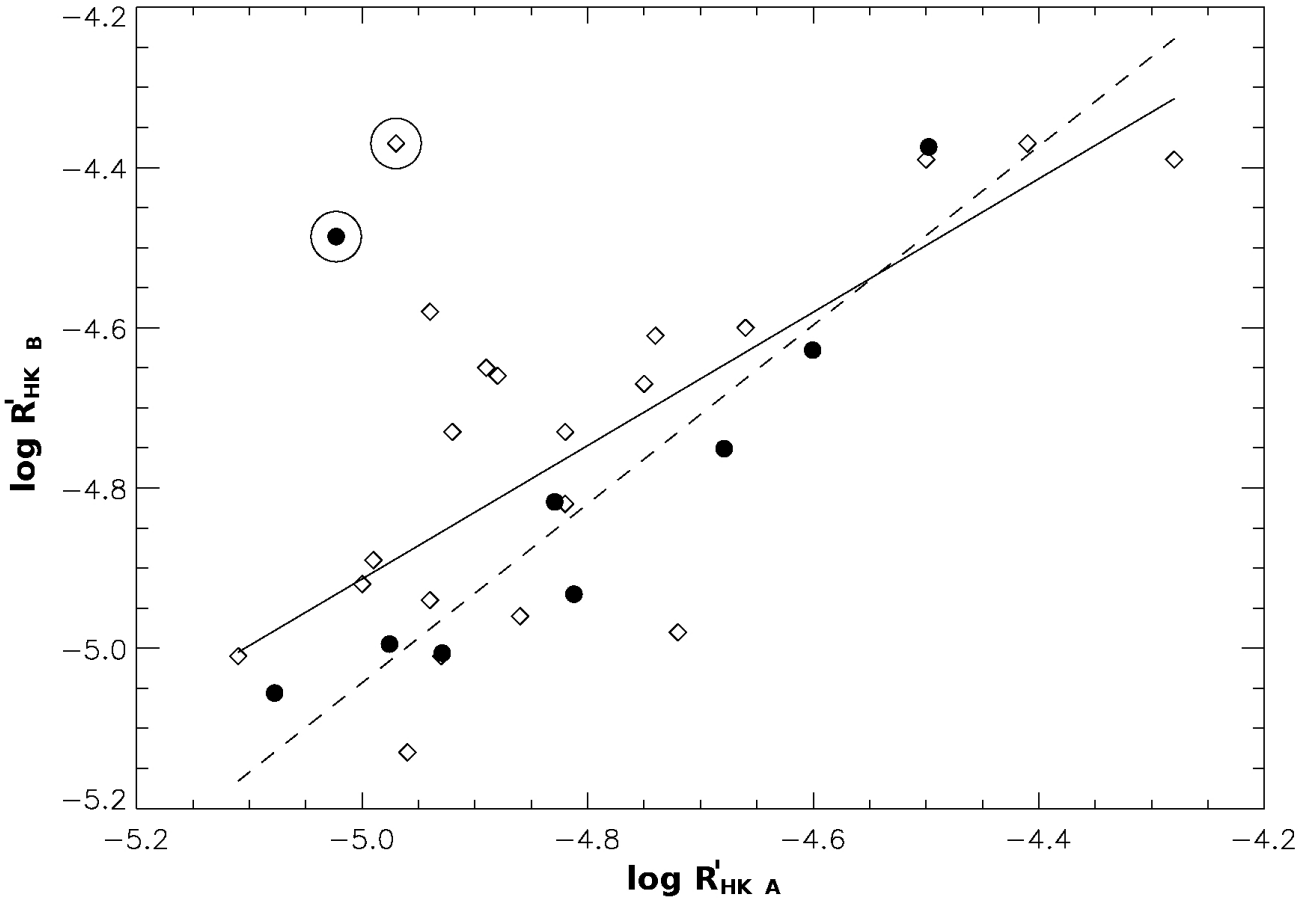
Rotation and chromospheric activity (Mamajek & Hillenbrand 2008)



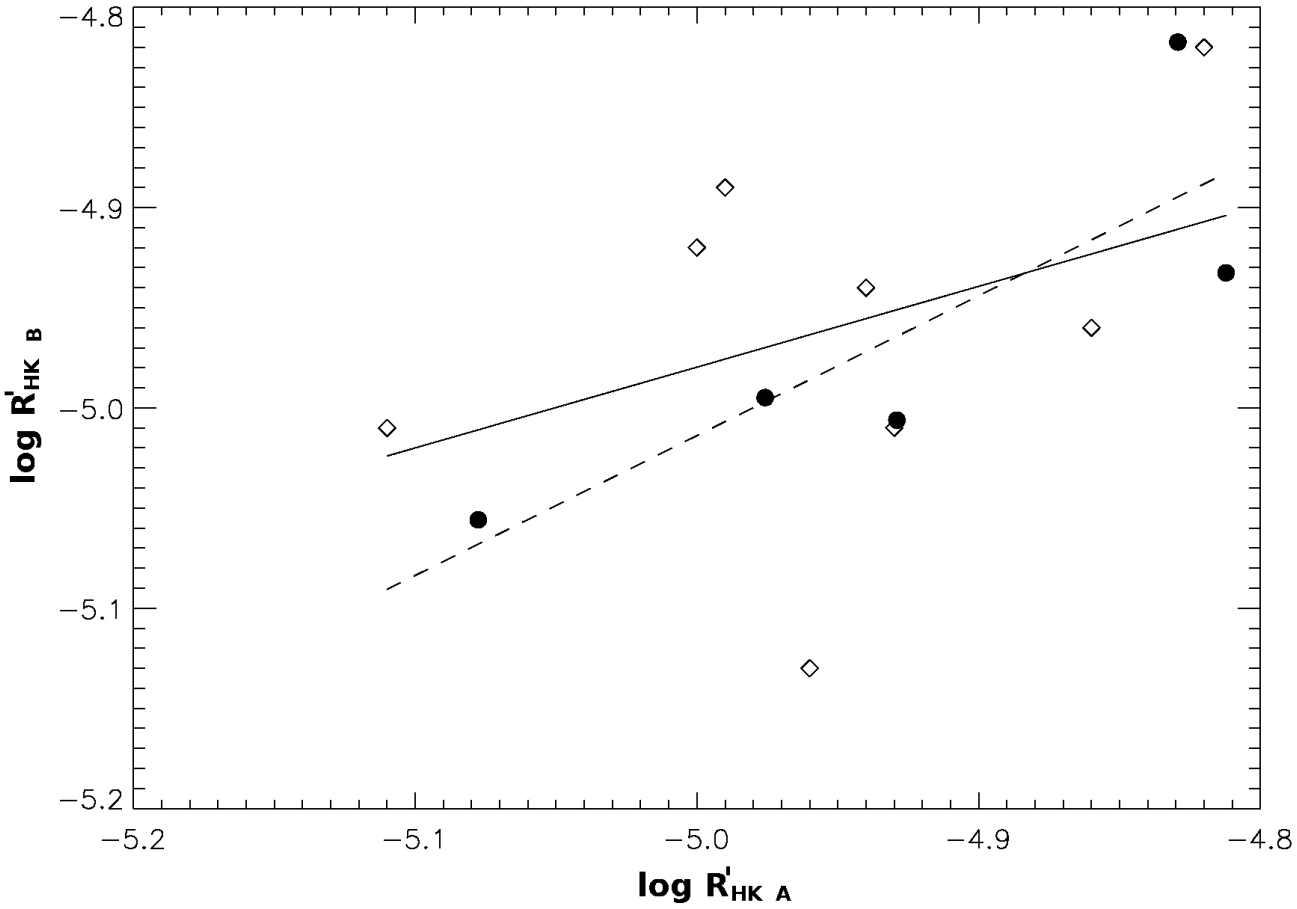
Rotation and chromospheric activity (Mamajek & Hillenbrand 2008)



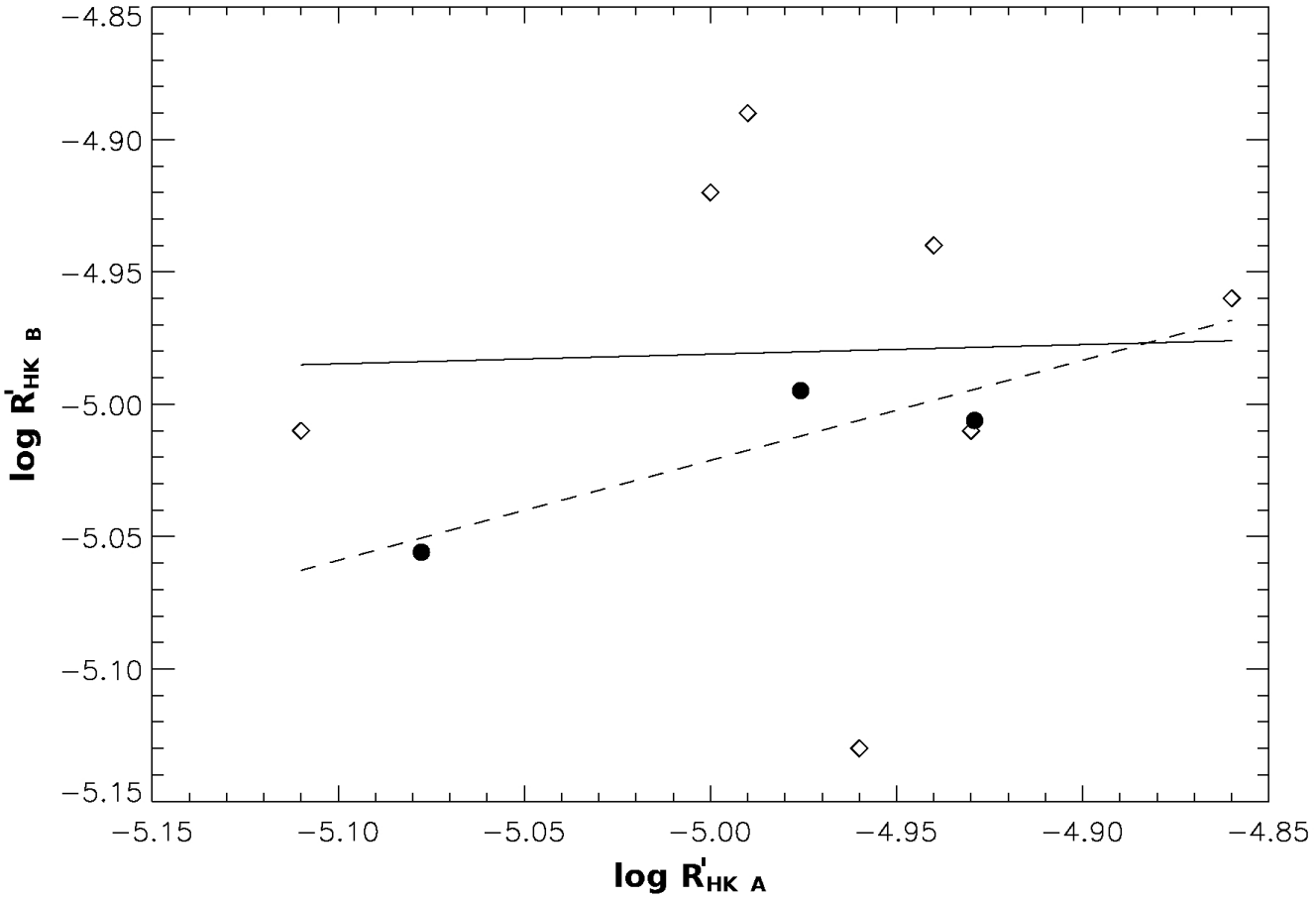
Binaries (Mamajek & Hillenbrand 2008)



Binaries (Mamajek & Hillenbrand 2008)



Binaries (Mamajek & Hillenbrand 2008)



Conclusions

- Considering all available data on chromspheric activity, all indications of a $CA \propto \sqrt{1/t}$ kind of law, vanish
- There is evolution, but it stops after ~2Gyr
- Environment may play a role (M67 is more active than solar-age field stars)