

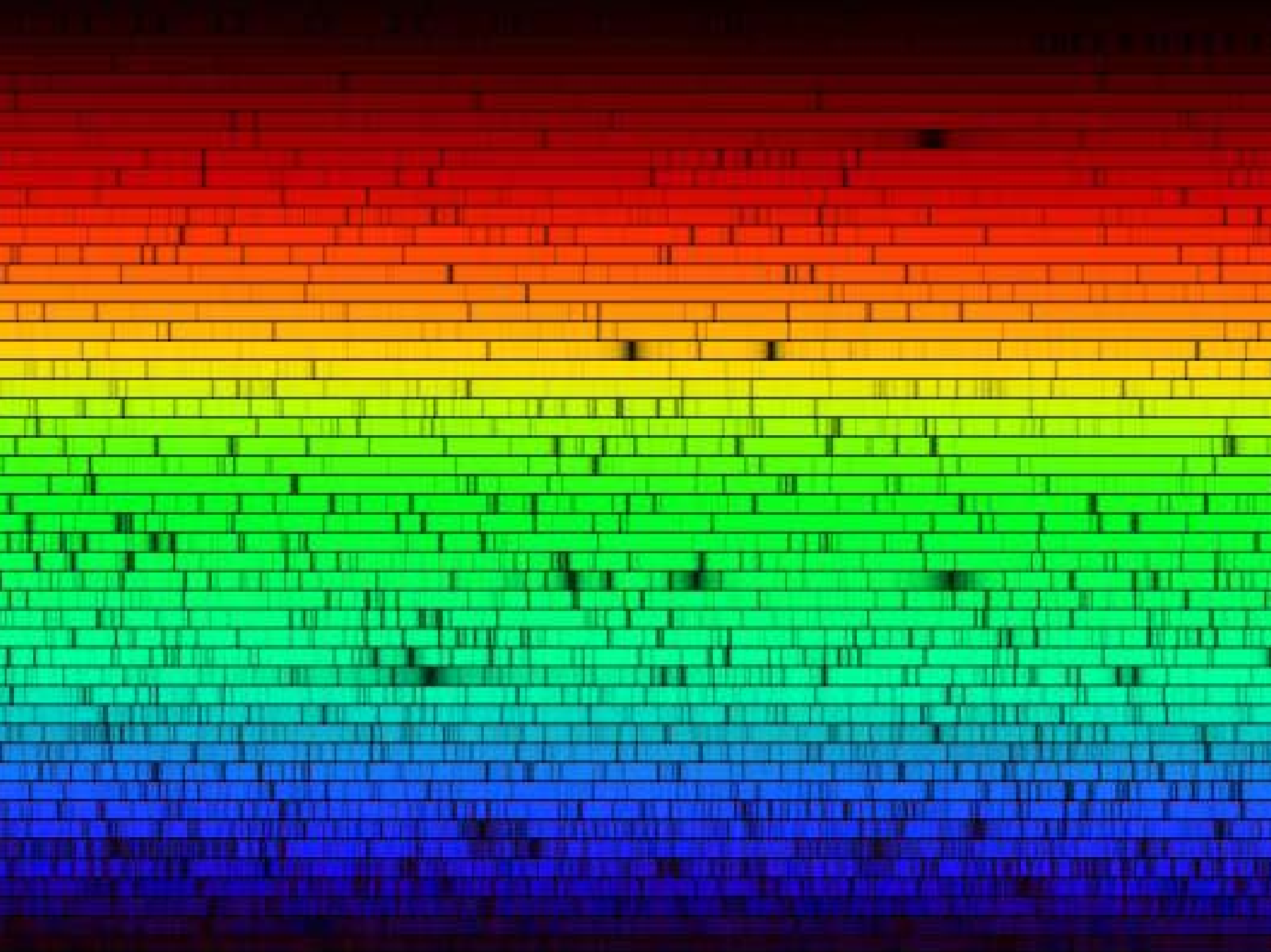
MOLECULAR LINES IN SUNSPOT SPECTRA

S.P. Bagare

In-house meeting of I I A

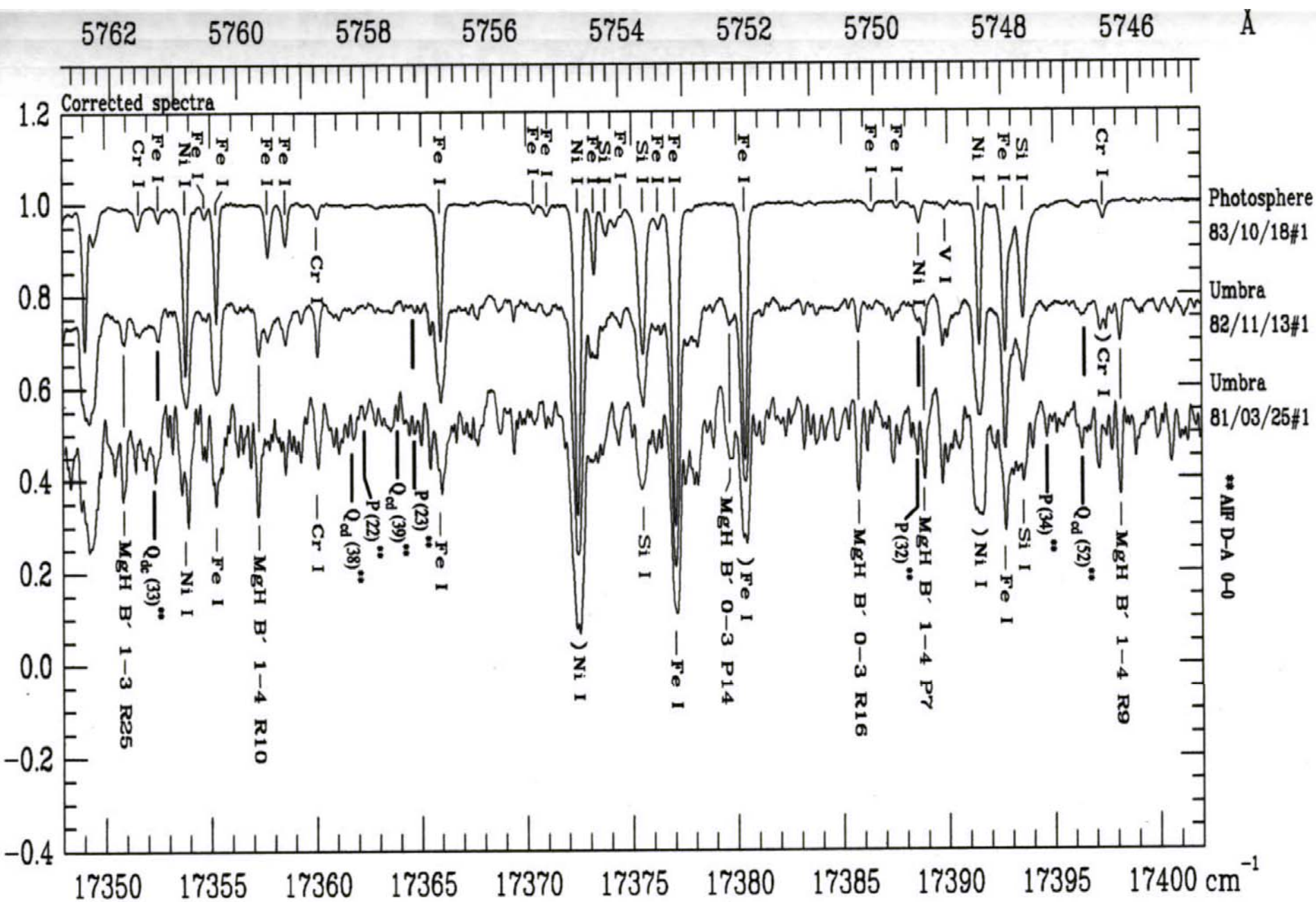
17 – 18 April, 2006

Work carried out by K.Balachandra Kumar for Ph.D. thesis submitted by the end of 2005 to Madurai Kamaraj University.



Molecular transitions

- Electronic transitions in the visible – rotational lines of the vibrational bands resolved in the high resolution FTS spectra of solar atmosphere – obtained at KPNO – NSO digital archive
- Pure vibrational and rotational lines in the infra red and radio regime



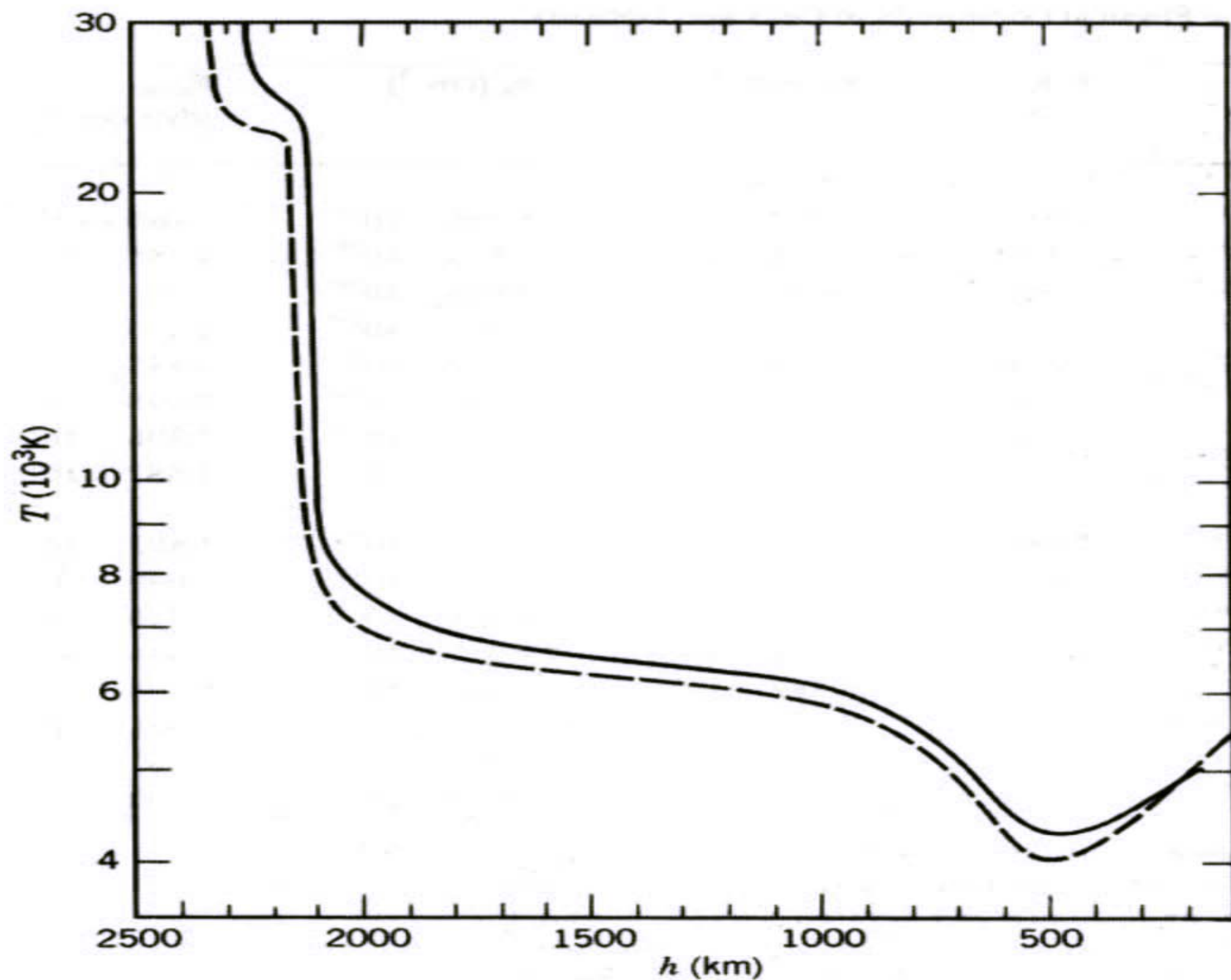


Fig. 9-7 Plot of temperatures versus height in the chromosphere for the cells (dashed) and network (solid). Adapted with permission from J. Vernazza, E. Avrett, and R. Loeser, *Astrophys. J. Suppl.*, **45**, 635 (1981).

MOLECULAR LINE OBSERVATIONS

- Temperature and pressure fluctuations in the photosphere
- Imaging of T-min region
- Intensity oscillations in active regions
- Evershed flow in penumbrae
- Excitation temperature - layer of formation
- Isotopic abundances
- G – band (CH at 4310 Å), excellent proxy for magnetic features. CN at 3883 better contrast !

Diatoms in sunspot umbrae

- Rowland(1895) to Wallace & Hinkle(2001) identified and confirmed presence of CN, TiO, CaH, CH, MgH, AlH, and FeH
- Presence uncertain for CN, C₂ Swan, MgO, ZrO, VO, CrH, etc.
- Search negative for BH, BN, BO, etc.
- Wohl (1971) – extensive search

Prerequisites for identification

- Reliable vibrational and rotational analysis data providing the molecular constants
- Frank Condon Factors – transition probabilities
- High resolution umbral spectra

Present study

- Search for AIF transitions, suspected to be present by Wohl (1971)
- Transition probabilities significant as determined by Murty (1977), Joshi et al. (1982), Kumar, Rajamanickam & Bagare (2002), Kumar, Bagare & Rajamanickam (2003, 2004) for 13 electronic transitions
- Searched for 1497 lines due to 11 band systems of 5 electronic transitions in the range of 4400 – 9000 Å

Methodology

- Lines classified as present, shoulder, merged (strong atomic or other molecular line present) or doubtful (difference from laboratory wavelength higher than 0.02 Å)
- Present plus shoulder taken as identified

Method of coincidence

- In order that identifications are not statistical coincidences only, we define

$$C = N \left[1 - (1 - 2x/X)^M \right],$$

N total number of lines present

X width of region in A

M number of lines searched for

x tolerated departure in A (0.02)

Complementary test

- Intensity distribution in P, Q, and R branches, and the pattern of peaking of absorption maximum studied for confirmation of identification

Table I Parameters to evaluate the presence of AlF transitions

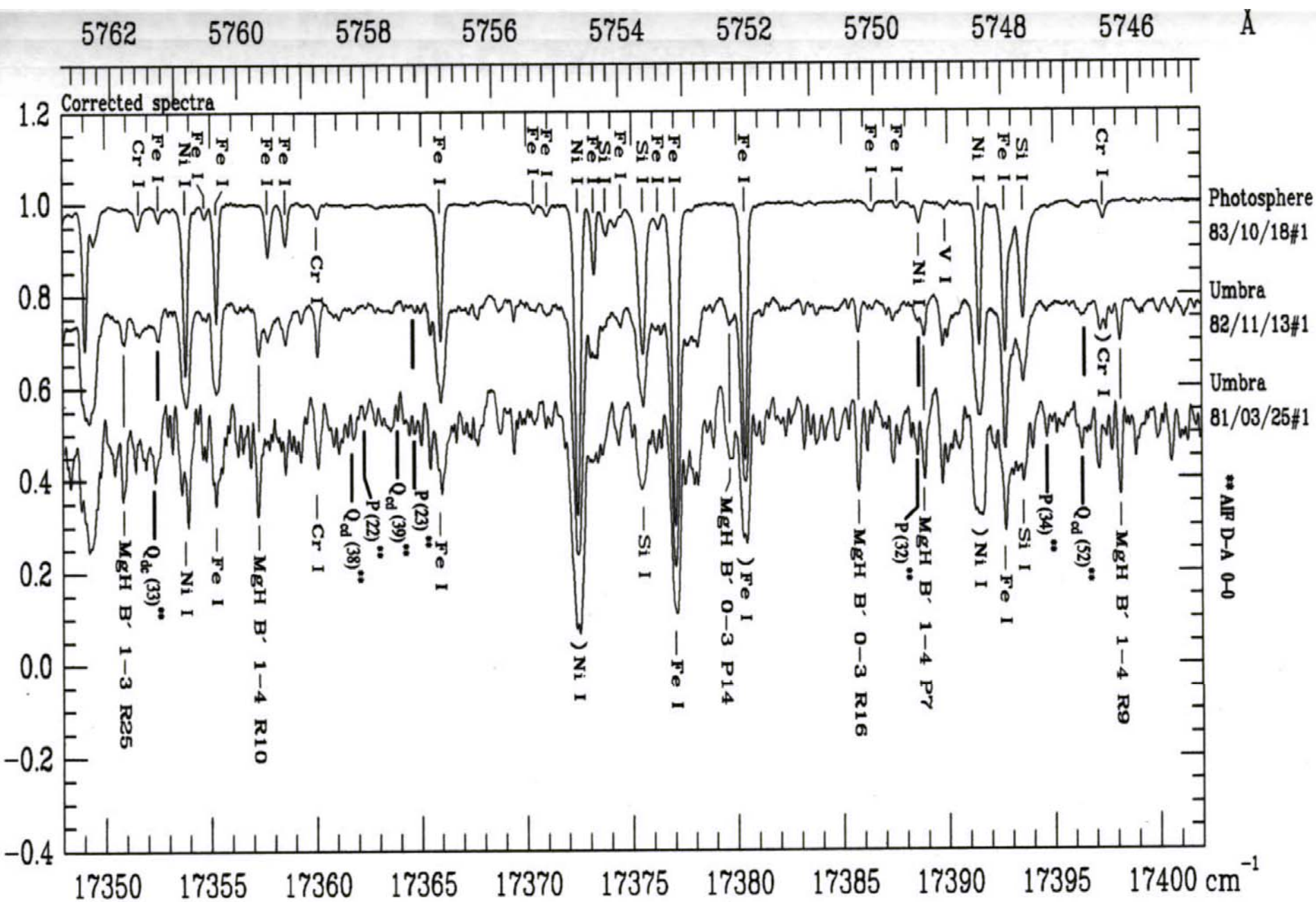
Transition	Band	FCF	C-index	I-parameter*
C - A	(0,0)	0.717	49	64 (208)
	(0,1)	0.234	16	34 (121)
	(0,2)	0.043	18	69 (120)
	(1,0)	0.241	42	27 (130)
	(1,1)	0.312	41	28 (158)
	(1,2)	0.320	24	35 (104)
	(0,0)	0.814	09	86 (139)
D - A	(0,1)	0.165	38	68 (108)
F - A	(0,0)	0.674	63	65 (199)
G - A	(0,0)	0.527	33	48 (092)
F - B	(0,0)	0.945	41	78 (118)

* Total number of lines searched for is given in parentheses.

Table II Rotational lines identified for C-A (0,0)

Line	λ Å	Line	λ Å	Line	λ Å
Q83	7117.73	R40	7188.74 ^S	Q27	7229.40 ^S
Q82	7120.73	R39	7190.75	P47	7231.11
Q81	7123.70	Q49	7199.20 ^S	P45	7233.27
R66	7123.98 ^S	P68	7199.32 ^S	Q20	7235.40
Q79	7129.52 ^S	Q48	7200.96 ^S	Q18	7236.78
R63	7132.66 ^S	P65	7204.90	R7	7236.93 ^S
R61	7138.26 ^S	Q44	7207.60	Q17	7237.40
Q72	7148.78	P63	7208.43 ^S	P36	7241.11
Q69	7156.46 ^S	Q43	7209.16 ^S	Q6	7242.10
R54	7156.80	R27*	7212.22	Q4*	7242.46 ^S
Q68	7158.95 ^S	Q41	7212.22	P34*	7242.46 ^S
Q67	7161.41	R25	7215.37 ^S	Q3	7242.63 ^S
Q66*	7163.82	R24	7216.85 ^S	Q2	7242.73
Q65	7166.18	Q37	7217.83 ^S	P3	7244.48
Q64	7168.53 ^S	Q36	7219.16 ^S	P29	7245.40
R49	7168.98 ^S	R21	7221.12	P5	7245.40
R48	7171.32	R18	7225.08	P26	7246.31
R46	7175.89 ^S	P52	7225.08	P22	7247.37
Q59	7179.66	Q31	7225.21	P12	7247.48 ^S
R44	7180.30	R16	7227.57 ^S	P21	7247.55
R43	7182.46 ^S	P50	7227.57 ^S		
Q57	7184.02 ^S	R15	7228.73		

Note: Lines marked * in Tables II to XI, could not be measured accurately during rotational analysis by Naudé and Hugo (1953, 1954). The lines marked ^S in Tables II to X lie on the shoulder of a strong atomic or other molecular line.



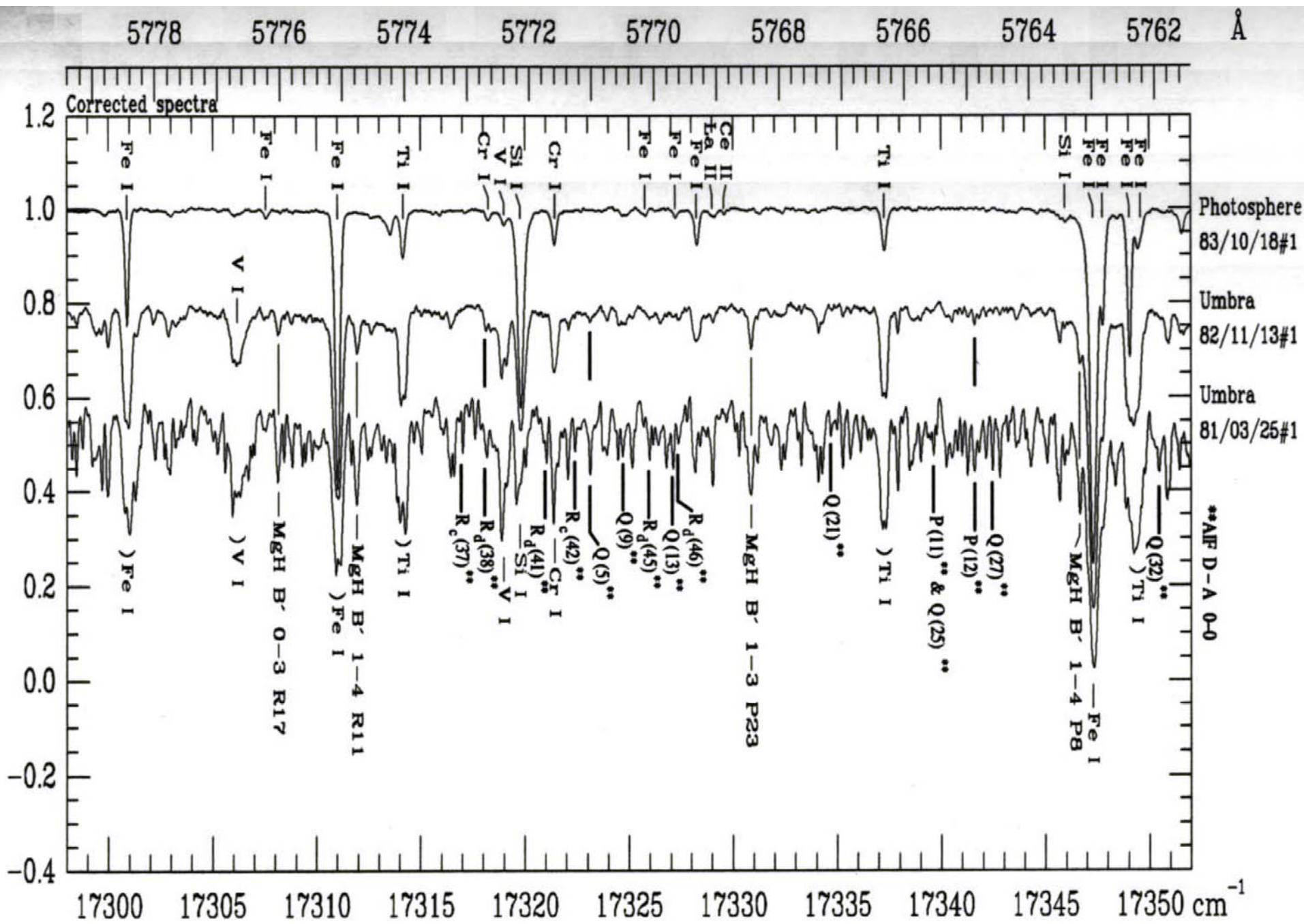


Table XI Estimated equivalent width values for D-A (0,0) & D-A (0,1)

D - A (0,0)			D - A (0,1)		
Line	λ Å	W mÅ	Line	λ Å	W mÅ
Q _{dc} 55*	5743.72	06.0	Q _{dc} 49	6018.74	17.6
Q _{cd} 55*	5743.81	11.5	P29 & P28	6025.90	13.6
Q _{cd} 52	5746.72	12.2	Q _{cd} 42	6026.37	04.9
P34*	5747.32	09.2	Q _{cd} 41	6027.42	09.7
P32*	5749.27	13.9	P23	6031.08	05.4
P23	5757.17	10.1	P22 & Q36	6032.01	10.5
P22	5757.96	07.3	P17	6036.46	18.4
Q _{cd} 38	5758.13	10.3	P12	6040.33	15.9
Q _{cd} 33	5761.30	13.0	Q16	6044.47	10.4
Q32*	5761.91	18.5	Q12	6045.84	06.6
Q27	5764.58	08.4	Q4	6047.42	06.5
P12	5764.91	08.4	R32	6048.75	08.0
P11 & Q25	5765.52	07.4	R23	6050.93	11.8
Q21	5767.20	04.7	P39*	6237.60	12.3
R _d 46	5769.64	07.9	P34*	6244.49	11.6
Q13	5769.67	08.2	P31*	6248.34	07.7
R _d 45	5770.09	08.8	P30*	6249.56	22.0
Q9 & R _d 44*	5770.51	09.4			
Q5	5771.05	10.6			
R _C 42	5771.26	05.4			
R _d 41	5771.71	07.4			
R _d 38	5772.71	09.4			
R _c 37	5772.97	03.3			

$$\log(W/J) = \text{const.} - \frac{Bhc}{2.3kT} J(J+1),$$

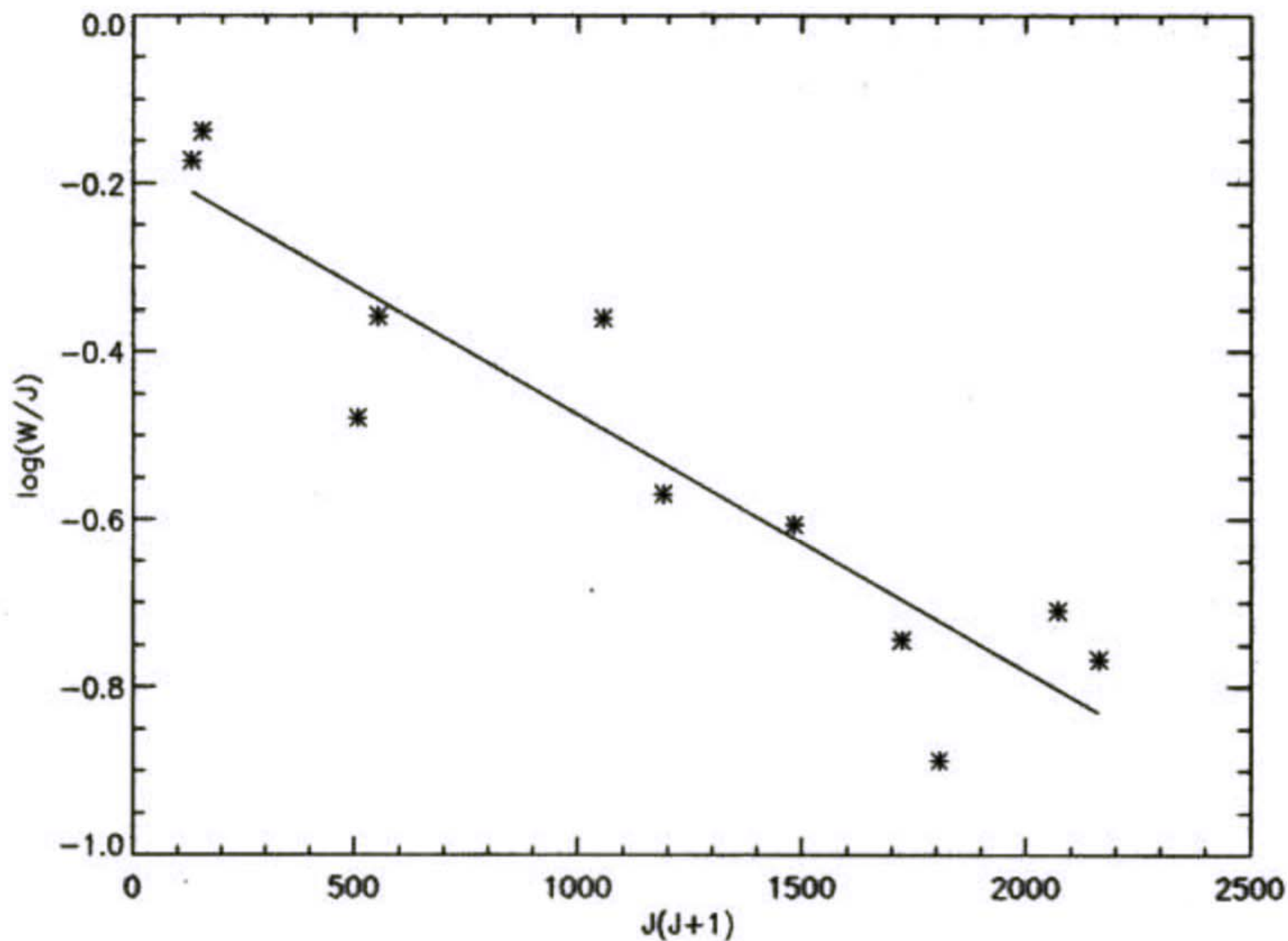


Fig. 3 Plot of $J(J+1)$ versus $\log(W/J)$ for D - A (0,0) band of AlF. Only the P and R branch lines are used, as described in the text.

Effective rotational temperature

- Reported values of umbral T use mostly the observations of TiO, MgH, and FeH
- Present values in the range of 1740 to 4800 K
- 1240 ± 120 K for D – A (0,0)
- 2390 ± 400 K for F – A (0,0)

Conclusions

- Over 600 lines due to 11 bands of AlF identified and confirmed
- Effective rotational temperature estimated for relatively 'cool' umbra
- A 10 Å region identified with predominantly AlF lines present – potential diagnostic window for T and oscillation study (low scatter from neighbouring photosphere)
- Need for T modeling of umbrae