POSSIBILITIES AND ATTEMPTS TO DETERMINE THE DIFFERENTIAL ROTATION ON F-TYPE MAIN-SEQUENCE STARS

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Abstract : A preliminary analysis of spectral lines by Fourier transformation was used to determine upper limits of differential rotation for 11 F-type stars, mainly from the main-sequence. No evidence for a much steeper differential rotation on these stars than on the Sun could be found.

1. INTRODUCTION

Differential rotation on stars may be determined by
(1) - a time analysis of changes of the stellar radiation due to the rotation of 'activity regions' and their drifts in latitude during a stellar activity cycle.
(2) - an analysis of differences of rotationally broadened spectral line profiles as compared to spectral lines from rigid body rotation.

While the first method is not yet proven for the Sun (but see Vogt,1981), the second is discussed since the pioneering work of Gray(1977):
If the differential effect is written in terms of angular velocity as a function of colatitude ψ

$$\omega(\psi) = \omega_o + \omega_2 \sin^2 \psi \qquad [1]$$

then the parameter $\alpha = \omega_2/(\omega_o + \omega_2)$ [2]

is a measure of the differential effect.
The Fourier transforms of the line profiles show characteristics of the differential effect: The strength, both height and width, of the first sidelobe decreases with increasing α, while the second sidelobe is nearly constant. For $\alpha \simeq 0.5$ the first and second sidelobes are about the same.
Bruning(1981) and independently Garcia-Alegre et al.(1982) showed that this effect of the differential rotation can even be found in artificial integrated spectral lines

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contaminated by CLV, blends, line asymmetries, line shifts etc. For non-equator-on cases the effect produces even larger changes. They also confirmed that spectral line profiles with a high signal-to-noise ratio are needed to determine the sidelobes.
Gray(1982) reported the analysis of 7 F-type stars and found observational evidence against differential rotation in F stars.
The aim of this work was to investigate stars with higher rotation velocities and also compare the results with those of Gray(1982) and predictions of Belvedere et al.(1980).

2. OBSERVATIONS

The spectra were obtained with the linear RETICON array in the Coudé Echelle Spectrometer (CES) at the 1.4 m Coudé Auxiliary Telescope (CAT) of the European Southern Observatory (ESO) at La Silla,Chile, June 9 until 17,1982. The red light path was used and the exposure times were in general 0.5 h but sometimes less due to clouds. The spectral resolution was in general 100 000, in some cases 150 000. The wavelength region was 5534.4 to 5597.6 Å centered on the non-split Fe line at 5576.1 Å. In some cases also the wavelength region used by Gray(1982) from 6221.9 to 6274.2 Å was used. The pixel spacing was 23.1 mÅ in the first and 28 mÅ in the second case. The signal-to-noise ratio obtained in the continua of the spectra was in general 200 to 300. The census of data is given in Table 1, where the stars are arranged according to increasing rotation velocities given by Uesugi(1976).

3. REDUCTIONS AND RESULTS

The spectral line analysis was performed July 19-24, 1982 using the Image Handling Package (IHAP) at the ESO headquarter at Garching. The dark current and flat field corrections had to be performed separately for each spectrum. No smoothing of the original data was applied.
In a first analysis of the 36 useful spectra only the Fe 5576.1 Å or the Fe 6252.6 Å line were analysed. Most of the Fourier transformed spectral lines showed no indications for values of $\alpha > 0.4$ (see Table 1). Typical Fourier transformed spectral lines are given in double log scale in Fig.1. In those cases, where an indication for a steeper differential rotation was found, in addition the spectral lines Fe 5569.6, Ca 5582.0 and Fe 5586.8 Å were analysed in the shorter wavelength region and the spectral lines Fe/Si 6254.2, Fe 6256.4, Fe 6265.1, Fe 6230.7 and Fe 6232.6 Å for the longer wavelength region.

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Table 1 : Census of data of the analysed F-type stars

star name	spectral type	m_{vis} [mag]	v_{rot} [km/s] Uesugi	v_{rot} [km/s] this work	first results	remarks
ξ OPH	F 2 V	4.39	0	24	1S, 7N,	G1
γ SER	F 6 IV-V	3.89	8	11	1S,	G2
γ PAV	F 8 V	4.22	10	4-11	1S, 4N	
τ BOO	F 7 V	4.50	14	15-22	2S, 3N,	G3
α CRV	F 2 V	4.03	25	34-38	3N	
ψ CAP	F 5 V	4.14	37	48-61	1S, 5N	
ω PSC	F 3 V	4.01	38	48	2N	
μ VIR	F 3 IV	3.89	60	77	1N	
ζ SER	F 3 V	4.62	80	97	2N	
δ AQL	F 0 IV	3.36	85	97-108	2S	
η SCO	F 2 V	3.33	150	153	0.5S,0.5N,	R

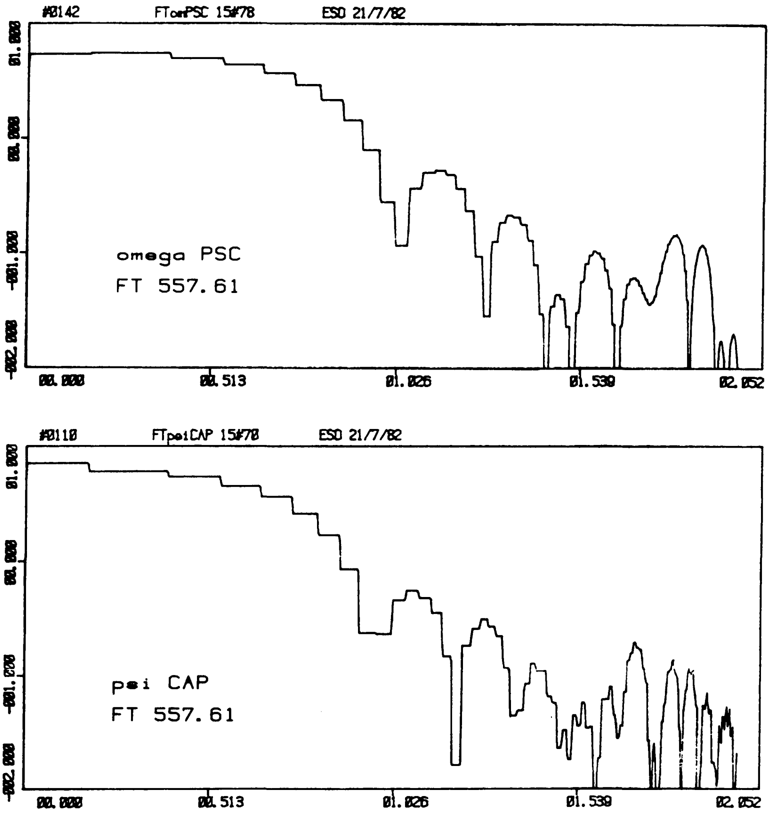

Fig. 1 : Typical examples of Fourier transforms of the line Fe 5576.1 Å. Given are normalized Fourier amplitudes against the first 200 points of the transform in a double log scale. The Fourier frequency spacing is about 0.0021 s/km.

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In no case an indication for a value of $\alpha > 0.4$ remained for the majority of the spectral lines analysed from any star. In addition the rotation velocities for the stars investigated were determined from the zeros of the Fourier transforms; they are also given in Table 1.

4. CONCLUSIONS

No evidence could be found for a steep differential rotation on F-type stars as claimed by Belvedere et al.(1980) with $\alpha > 0.5$. This result is in agreement with that of Gray(1982), although in general other spectral lines and mainly different stars were used.
A more detailed analysis - comparable to the 'modeling' done by Gray(1982) - is needed to reduce the upper limit of $\alpha \simeq 0.4$ and to determine the parameters with more precision.

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REMARKS TO TABLE 1 (previous page)

S : indication for steep differential rotation
N : no indication for steep differential rotation
R : spectral lines Na D 5890 and 5896 Å analysed, one with and the other without indication for steep differential rotation
other spectral classifications of this star : F 0 IVn and F 2 III

from Gray(1982): G1 : v_{rot} = 20.6 km/s, α = -0.15
G2 : v_{rot} = 10.8 km/s
G3 : v_{rot} = 14.8 km/s, α = 0.27

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DISCUSSION

SODERBLOM: Your data have a very high signal-to-noise ratio and very high spectral resolution, yet your values of $v \sin i$ seem very rough; for example, for one star a range of 4 to 11 km s^{-1} is given. Why cannot the $v \sin i$ be specified more precisely? If the $v \sin i$ is poorly determined, how can differential rotation be detected?

WÖHL: In the preliminary analysis I did not try to determine the rotational velocities very accurately, but just from the double-log plots. In the case of slowly rotating stars, influences from motions in the atmosphere of the star have to be taken into account. They depend on the individual spectral line. In addition, more careful corrections (averaging of several dark currents, flat fields, etc.) will hopefully improve the internal accuracy within a detailed analysis. Nevertheless the statement about the upper limit of the differential rotation parameter α can be made, because then only the first sidelobe is compared with the second in height and width, not depending on the position, which gives the rotational velocity.

GILMAN: Do any of the stars you observed have magnetic activity, either cyclic or non-cyclic?

WÖHL: I did not yet check this, because I selected the stars according to the spectral type and rotational velocity. In addition I was guided by theories, which claim that differential rotation is independent of magnetic activity.

SODERBLOM: Response to Gilman: At least one of the stars, τ Boo = HD 120136, was illustrated by Dr. Vaughan earlier. It had at best only a slight cyclic variation.

GILMAN: The reason why I asked is that it is my opinion that stars having cyclic activity are the ones that have large differential rotations, and the ones which do not are likely to have small differential rotation, because differential rotation plays such a prominent role in producing a cycle.

GRAY: We should look carefully at the list of program stars used here. They are mostly early F stars, and for them the convection zones are thought to be very thin. So we might not expect differential rotation in most of these stars, and the calculations of Belvedere, Paterno, and Stix may not predict any.

WÖHL: As I understood the paper of Belvedere, Paterno, and Stix the steep differential rotation is mainly caused by the high rotational velocity. Therefore I selected these early F-type stars, which still should have convection zones.

STIX: I must admit that our model indeed produced such large differential rotation, if only a (even thin) convection zone was present. So maybe we have to modify this theory a bit.