### A STUDY OF SOLAR MAGNETIC AND VELOCITY FIELDS

Shibu K. Mathew

Ph.D. Thesis September 1998

Physical Research Laboratory Ahmedabad 380 009, India

#### A STUDY OF SOLAR MAGNETIC AND VELOCITY FIELDS

Shibu K. Mathew

Physical Research Laboratory Ahmedabad 380 009, India

A thesis submitted to the Gujarat University for the Degree of Doctor of Philosophy

September 1998

In memory of my dear mother

### Smt. Thankamma Kunchandy

#### CERTIFICATE

I hereby declare that the work presented in this thesis is original and has not formed the basis for the award of any degree or diploma by any University or Institution.

Shibu K. Mathew

(Author)

Physical Research Laboratory Ahmedabad - 380 009 (India)

**CERTIFIED BY** 

Dr. Ashok N. M.

(Thesis Supervisor)

Reader Astronomy and Astrophysics Division Physical Research Laboratory Ahmedabad - 380 009 (India)

#### Acknowledgments

I want to express my heartfelt gratitude to Prof. A. Bhatnagar, my guide, who posed the thesis subject and guided me all along the way in my research with his long experience in solar physics and especially in the field of instrumentation.

Dr. Ambastha helped me through out my research and specially during the later stages with his acumen in the field and it would be no hyperbole to say that he brought the thesis in final shape. No words can express my gratitude to him.

I want to express my gratitude to Dr. N. M. Ashok for helping me in fulfilling the statutory requirements and his moral, academic and guidance in my research.

Thanks are also due to Dr. Debi Prasad who was always available in the time of difficulty with his practical suggestions. Nandita's help, both in the hostel and the observatory require special mention. I want to express my deep gratitude to her.

I am thankful to Dr. R. M. Jain and Dr. S. C. Tripathy for their help in my research in various ways.

Neerav, Brajesh and Lokesh provided me nice company in hostel and in the observatory. I want to express my thanks to Prof. Jack Harvey and Prof. Bill Livingston for their useful suggestions and comments on my research. Thanks are also due to Dr. Venkatakrishnan for his valuable help. Also, I want to express my thanks to Prof. Peter Foukal for his kind words and encouragement.

Thanks are due to the Director, PRL and all the Academic committee members for their frequent assessment of my work. Especially I am thankful to Prof. M. R. Deshpande, Prof. J. N. Goswami, Prof. V. B. Sheory, Dr. T. Chandraskehar and Prof. B. G. Anandarao for their continued interest in my work.

Sh. B. L. Paneri with his precision in fabrication of mechanical instrument was of immense help in building the magnetograph. All the mechanical components required for the magnetograph were designed and fabricated by him. I want to express my special thanks to him.

SOHO/MDI magnetogram used for the comparison is kindly provided by SOI-MDI group.

Especially, I am thankful to Prof. Philip Scherrer for the SOHO magnetograms. Calibrated GONG magnetograms were kindly provided by Dr. Frank Hill, I express my thanks to him. The help of Dr. Mitzi L. Adams, for obtaining the MSFC magnetogram is acknowledged. The high voltage power supply for KD\*P modulator was designed and fabricated at Space Application Center (SAC), for which I acknowledge the contributions of Dr. S. S. Rana, Sh. Arora and his group members. Dr. Balasubramaniam and Dr. Vyas from SAC are acknowledged for their help in optical coating.

Mr. Raju Koshy and his family provided me moral help and a home away home, and also a touch of my native land Kerala with his frequent invitations for lunch and dinners. I express my heart felt gratitude to Sh. Porwal and family for their love, homely affection, help and support extended to me. I also remember Late Smt. Sardalia for her moral support.

Thanks are also due to Sh. Gupta and Sh. Naresh for their technical help.

I express my gratitude to Sh. Sanjay Bhatnagar for helping me in administrative matters. Sh. Rakesh Jaroli, Sh. Ram Chandra Carpenter and Sh. Laxmilal Suthar provided me all possible assistance.

I want to record my thanks to Sh. Shankar Lal Paliwal, Sh. Jagdish and Sh. Dal Chand for their support.

Thanks to you, Poulose, Watson, Biju, Clement and Shibu for all your love, advises, help and support and also for your frequent moral boosting visits.

I remember with gratitude my batch mates Sandeep, Debabrat, Anshu, Prashant, Chakraborty and friends Lucky and Azim. I remember with pleasure the company of Ranjana, Bala and Prathista during their short stay in the observatory.

I am thankful to all the PRL library and computer center staffs, especially Mrs. Barucha, Mrs. Giya and Mrs. Rohini for their support and help.

I remember with gratitude the support extended by Mrs. Bhatnagar, Mrs. Ambastha and Mrs. Debi Prasad.

Thanks to Sh. Pandey, Sh. Duve, Sh. George and their families for their advice, affection

and help.

Thanks are also due to Sh. Pukhraj Joshi for providing ration. Rukmeni Ben cooked patiently for all through these years.

I would especially like to mention Sh. Heera Lalji, ex-gardner, for his help during observations. I learnt a lot of values from his unassuming character.

Thanks are also due to all the security guards, especially Dinesh, Daval, Ramchandr and Barot for their timely cup of tea while working in the night.

None of it would have been possible with out the patient support and quite inspiration of my father. I do not think it is possible to express my feelings for them in words and I will not even try. My brothers John Mathew, K. Raju and sister-in-laws Ponnamma and Leelamma supported me with love, patience and affection especially during my hard time. I also want to express my thanks to my sisters, Leelamma, Kunjumole and Kunjukunjamma and my brother-in-laws Philip, Joykutty and David for their love, affection and support. I also remember with pleasure the real love and affection of my nephews and nieces Binu, Teena, Beena, Darshan, Jinu, Jeena, Jestine, Jinson and Jessy.

At last, thanks to "Chogum" for her patience to stay with me through out the thesis period, she is my cute cat.

#### **Research Publications**

 Solar photospheric and chromospheric observations using a Lithium Niobate Fabry-Perot etalon, 1997, Debi Prasad C., Shibu K. Mathew, Arvind Bhatnagar and Ashok Ambastha, Exp. Astronomy, 8, 125.

2. Fabry-Perot filter based solar video magnetograph, 1998, **Shibu K. Mathew**, Arvind Bhatnagar, Debi Prasad C., and Ashok Ambastha, A&AS (in Press).

3. A digital imaging multi-slit spectrograph for measurement of line-of-sight velocities on the Sun, 1998, Nandita Srivastava and Shibu K. Mathew, submitted to Solar Physics.

### Contents

1	Intr	roduction	1
	1.1	Sunspots as seats of strong magnetic fields	2
	1.2	Solar active regions, the center of solar activity	4
	1.3	Solar flares	5
		1.3.1 Flare in association with the magnetic field	9
		1.3.2 Solar flare models	12
	1.4	Solar magnetic field measurement	15
	1.5	Solar magnetographs	17
<b>2</b>	USC	O Video Magnetograph	19
	2.1	Principle of Solar Magnetograph	19
		2.1.1 Zeeman effect	20
		2.1.2 Stokes parameters	21
		2.1.3 Circular polarization measurement technique	24
	2.2	The optical layout of USO magnetograph	26
	2.3	Narrow band filter	28
		2.3.1 Theory of Fabry-Perot etalons	30
		2.3.2 Electro-optic effect in Lithium Niobate substrate	35
		2.3.3 Voltage tunable $LiNbO_3$ FP etalon	36
		2.3.4 Narrow band filters at CaI 6122 Å and H $\alpha$ 6563 Å $\ldots$	41
	2.4	Polarisation analyser	43

		2.4.1	KD*P Pockels cell modulator	44
		2.4.2	Calculation of quarter wave voltage for $\mathrm{KD}^*\mathrm{P}$ crystal $\hfill\h$	45
		2.4.3	Circular polarisation analyser	46
		2.4.4	Quarter-wave retardation, high voltage driver for KD*P electro-	
			optic modulator $\ldots$	47
		2.4.5	Bench test of the $KD^*P$ modulator	48
	2.5	Detect	or - Cohu 4710 series CCD camera	51
	2.6	Image	e acquisition and processing system	52
	2.7	Opera	tional modes of the magnetograph	56
		2.7.1	Magnetogram and CaI filtergrams	56
		2.7.2	Chromospheric H $\alpha$ filtergrams $\ldots \ldots \ldots$	58
3	Cal	ibratio	n and Comparison	59
	3.1	Calibr	ation of USO video magnetograms	60
		3.1.1	Profile line slope method in weak field approximation	61
		3.1.2	Calibration of the USO video magnetogram data	61
	3.2	Comp	arison of USO, SOHO/MDI and GONG magnetograms	64
		3.2.1	Correlation plot of calibrated USO and SOHO magnetograms	67
	3.3	Data a	acquisition and reduction methodology	68
		3.3.1	Format of the raw VMG data and initial processing	68
		3.3.2	Magnetic flux, gradient and potential field calculation $\ldots \ldots \ldots$	69
4	$\mathbf{Stu}$	dy of I	Magnetic Field Evolution	71
	4.1	Active	region NOAA 7843 observed during February 18-20, 1995	72
		4.1.1	Observations	72
		4.1.2	Discussions and Results	73
		4.1.3	Conclusion	80
	4.2	A rapi	dly evolving active region NOAA 8032 observed on April 15, 1997 $$	81
		4.2.1	Observations	81

		4.2.2	Discussion and results	84
		4.2.3	Conclusion	89
	4.3	Active	region NOAA 8038 observed during May 10 - 13, 1997	91
		4.3.1	Observation	91
		4.3.2	Discussion and Results	91
		4.3.3	Conclusion	101
	4.4	Summ	ary of results	102
5	Sun	nmary	and Future Plans	104
	5.1	Summ	ary	104
		5.1.1	Instrumentation	104
		5.1.2	Comparison and calibration of VMG	105
		5.1.3	Study of evolution of active regions	105
	5.2	Future	Plans	106
		5.2.1	Study of more active regions during the ascending phase of solar	
			cycle 23	106
		5.2.2	Calibration of magnetograph using different methods	107
		5.2.3	Vector magnetic field measurement	107
A	KD <sup>3</sup>	*P Hig	h Voltage Power Supply	111
в	$\mathbf{V}\mathbf{M}$	G Soft	ware - C Program	113

## List of Figures

1.1	Magnetogram and CaI images of a single sunspot active region NOAA 8038	3
1.2	A two ribbon flare in NOAA 6555	8
1.3	Gold and Hoyle solar flare model	13
1.4	Sturrock and Heyvaerts flare models	14
2.1	Zeeman effect	22
2.2	Stokes parameter	24
2.3	Longitudinal magnetic field measurement technique	25
2.4	Computed Stoke's $V$ parameter for different filter positions $\ldots \ldots \ldots$	26
2.5	Optical layout of USO Videomagnetograph	27
2.6	The block diagram of the optics, image acquisition system and control elec-	
	tronics	29
2.7	Multiple reflection model for analysing Fabry-Perot etalon	30
2.8	Transmission characteristics of a Fabry-Perot etalon	31
2.9	Basic interferometric arrangement of Fabry-Perot etalon	33
2.10	Constructional details of the solid state $LiNbO_3$ etalon	37
2.11	Experimental arrangement for determining the parameters of FP etalon $\ . \ .$	38
2.12	The observed and corrected Faby-Perot channel spectrum	39
2.13	Voltage tunability of $LiNbO_3$ Fabry-Perot etalon filter	40
2.14	Passband shift and profile broadening due to FP tilt angle	40
2.15	The measured frequency response of the $LiNbO_3$ Fabry-Perot etalon filter	41

2.16	The transmission peaks of CaI (6122 Å) and H $\alpha$ (6563 Å) pre-filters	42
2.17	Temperature tunability of CaI 6122Å pre-filter	43
2.18	Circular polarisation analyser	48
2.19	Time sequencing diagram showing the synchronisation of image acquisition	
	and KD*P switching	49
2.20	The optical arrangement for the KD*P bench test $\hfill \ldots \ldots \ldots \ldots \ldots$	49
2.21	Applied voltage versus retardance for $KD^*P$ modulator $\ldots \ldots \ldots \ldots$	50
2.22	$\mathrm{KD}^*\mathrm{P}$ modulation at 7Hz $\ldots$	51
2.23	Image acquisition system architecture	53
2.24	Flow chart showing the operation involved in a single cycle of image acquisition	55
21	Intensity for different filter position plotted against the wavelength offset	62
2.0	The slope of the line profile	62
0.2 2.2	The full disk memotograms used for comparison	65
0.0 9.4	Persplution offset	66
0.4 9.5		00
3.0 2.6	The SOHO and rotation corrected USO magnetograms	01
3.0	Scatter plot made between the USO and SOHO longitudinal magnetic fields	08
4.1	Magnetogram , CaI and H $\alpha$ images of NOAA 7843 $\hdots$	72
4.2	Magnetogram , CaI and H $\alpha$ images of NOAA 7843 on 19 Feb 95 $\hfill$	74
4.3	Computed potential field overlaid on ${\rm H}\alpha$ and CaI images, 19 Feb 1995,	
	05:03 UT	77
4.4	Computed potential field overlaid on ${\rm H}\alpha$ and CaI images, 19 Feb 1995,	
	06:54 UT	78
4.5	Computed potential field overlaid on ${\rm H}\alpha$ and CaI images, 20 Feb 1995,	
	05:03 UT	79
4.6	NOAA 8032, GOES X-ray flare data on 15 April 1997	81
4.7	The 6122 Å continuum image of the active region NOAA 8032 taken on 15 $$	
	April 1997	82

4	1.8	The evolution of longitudinal magnetic field for NOAA 8032	83
4	1.9	Magnetic field gradient in active region NOAA $8032$ taken on 15 April 1997	86
4	1.10	The calculated potential field for NOAA 8032	88
4	1.11	The SOHO/EIT image for the active region NOAA 8032	89
4	1.12	Magnetograms and CaI images of NOAA 8038	92
4	1.13	12 May 1997, 1N/C1.3 flare	93
4	1.14	Network flux motion	95
4	1.15	Proper motion of the network fluxes	96
4	1.16	Velocity distribution of network magnetic flux elements	97
4	1.17	Network flux motion	99
4	1.18	Magnetic flux cancellation	.00
ЦU	5.1	The scheme for vector magnetic field measurement	.08
A	<b>A</b> .1	KD*P power supply 1	.12

### List of Tables

1.1	Classification scheme for flares
2.1	Narrow band filter parameters
2.2	Specifications of the Meadowlark Pockels cell modulator 45
2.3	Specifications of the Cohu 4710 series CCD camera
4.1	Flux changes at the location of EFRs
4.2	Flux cancellation at the flaring site on May 12, 1997
5.1	Full vector magnetic field measurement

## For Fulltext Please Contact

## То

# Author