The magnetic solar corona as revealed by polarimetry

Report of the conference held at Toulouse, Nov 4th -6th 2014

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November 19, 2014

1 The contributions

In 1967 a meeting at Bagnères de Bigorre counted with no less than 12 active coronagraphs around the world. Few survive today. This meeting put together 4 of the today surviving instruments and the only ones renewing instrumeantion in the goal of measuring the coronal magnetic fields: Those managed or used by the High Altitude Observatory (Mauna Loa and Sacramento Peak), the observatory of the Slovak Academy of Sciences at Lomnicky Stit and Pic du Midi.

Measuring the coronal magnetic field is a key to the understanding of not just the corona itself and the recurring question of its heating, but also as the source of most of the interplanetary activity, solar wind and space weather as the talks of A. Rouillard, A. Bemporad, B. Lavraud and F. Auchère reminded us.

Ground coronagraphs were the only means to observe the corona before access to space and to the ultraviolet became rutinary. The ease to observe the corona from space in the absence of non-instrumental scattered light but, most important, at wavelengths at which the solar disk is dark and all the emission comes from the corona signified a decline in the use of ground coronagraphs. That predominance of space instruments for coronal observations continues today and F. Auchere,B. Lavraud, L. Damé and S. Fineschi reviewed the upcoming proposals to measure the coronal magnetic field, many of them relying in the ultraviolet Lyα line and the Hanle effect. In all measurements, space instruments produce stable, high quality data rich in scientific content, but space instruments are often the transposition of successful techniques developped in ground telescopes. This is the future of the surviving coronagraphs: to develop the techniques that one day may be routinary in space. S. Tomczyk and L.Rachmeler presented the recent successes with ground coronagraphs, with CoMP, to measure the coronal field and S. Fineschi strengthenedt the necessary synergy between ground and space measurements.

J. Rybak, S. Tomczyk and L. Koechlin made the point on the actual state of the three main coronagrapic instruments still active in the world and the future plans of all of them. In all cases the measurement of the coronal magnetic field is the goal of the on-going or up-coming developements. While many instrumental improvements are required, as illustrated by the presentations of

G. Capobianco, M. Kozak, C.le Men and F. Landini, the actual measurement of the magnetic field heavily relies on the correct analysis and interpretation of the measured polarizations. L. Rachmeler illustrated this, and M. Faurobert and A. Lopez Ariste presented how similar interpretation problems have been addressed in the chromospheric resonance scattering polarization and in prominences. The intricacies of the Hanle effect are to be blamed for the difficulties in the interpretation but in general the corona is the place of all the possibles and the general undestanding of the radiative processes taking place in the corona is a sine-qua-non ingredient of these coronal projects as efusively illustrated by S. Koutchmy.

A few regrets have to be also put forward. While the role of the solar corona as the source of interplanetary activity was well stressed in several talks, we missed the comparison with other stellar coronae that can shed light on general and particular features of the solar corona

2 The Discussions

As an illustration, not of the scope, but of the workabouts of this meeting, a comparison was made with those famous Solvay meetings of the early XXth century. Proud as we are of our polarimetry and our coronal observations, the scope of our meeting is light-years more humble than those Solvay meetings, but the spirit we want to imitate in the limitation of the participants and in the fact that as important as the scheduled contributions were the discussions.

Not a single lecture on this workshop was longer than the many questions and comments that interrupted and continued it. And this was for the best. Particular mention must go to S. Koutchmy that enrichened every single contribution with his deep knowledge and long memory on the corona. A special recognition of his important role to this meeting was due. It is therefore probable that, in pale analogy to those Solvay meetings, this workshop will be remembered not for the scheduled contributions but for the discussions.

A core subject of discussion was on the objective reasons of the difficulty to observe the corona from the ground. A description of the main conclusion and collaboration project arising from these discusions follows. Before going into that it is worth however to expose a basic inconsistency in the observations of the solar corona.

The bottom line of the difficulties to see the corona is the solar disk light scattered by the earth atmosphere and our instruments. This scattered light is up to 1 million times stronger than coronal Thompson scattering intensities. The classic approach has obviously been to diminish the amount of scattered light from the disk. The basic ingredients of Lyot's coronagraph optical design and the selection of adequated observing spots are apparently a must to see the corona from the ground out of solar eclipses. It is apparent that in the 80 years or so since the times of Lyot nothing has happened in our technoloqy that eases this problem. This would earn coronagraphy a singular award in astronomy. Yet the argument of the amount of scattered light does not resist a deeper scrutiny. Let us take the case of the coronal green line, which is the strongest coronal emission line with intensities at 50×10^{-6} the disk intensity. Let us place ourselves in the worst-case scenario of observing this line at disk center, without coronagraph, but with a spectrograph. What we expect to see is the solar spectrum and a tiny

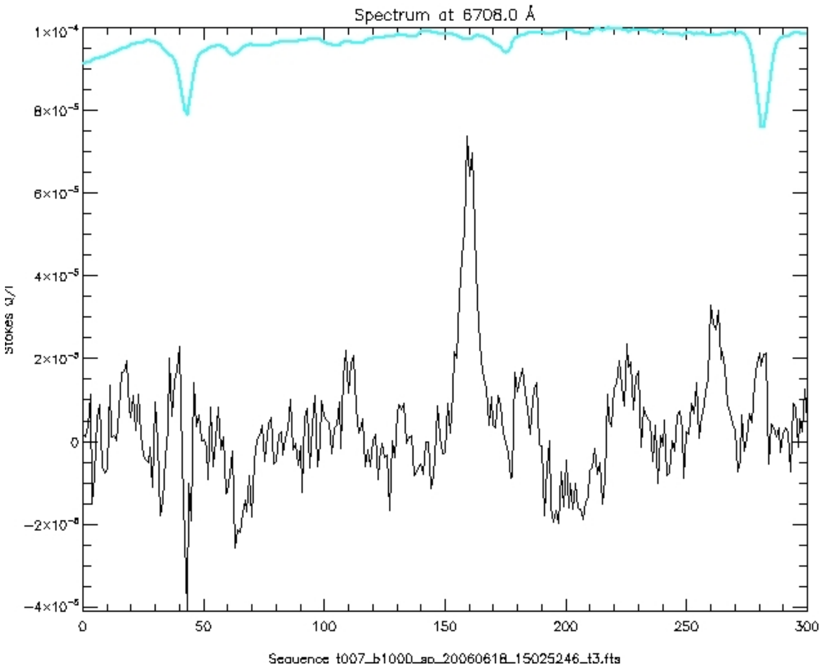

Figure 1: Linear polarization of the Li D_2 line observed with THEMIS with a noise of 10 parts-per-million, and a signal amplitude of 50 ppm, comparable to the coronal green line.

emission line adding up 5×10^{-5} to the continuum. The figure below shows an actual observation in THEMIS under these conditions with the difference that the observed line is Lithium D_2. This line is linearly polarized by resonance scattering at 5×10^{-5}. Polarization modulation techniques allow us to see such a low signal. Assuming that the coronal light could be modulated analogously to polarization, it appears that the green coronal light is observable at disk center even without the optical help of coronagraphs.

Our first argument implied the necessity of the purest skies in the world and the best optics to see the corona; our second argument implies that any telescope almost anywhere can see the corona provided the adequate measurement techniques are used. The truth is somewhere in the middle.

3 The Conclusions

Most of the discussions turned about the difficulty to observe the corona, let alone measuring its polarization. In reaction to those discussion, the participants identified 4 main handicaps:

- The quality of the sky at the observatories
- The levels of light pollution from the optical instrumens: both from optics and from stray light

- The performances of the detectors to sense a weak signal from a dominant background
- The observation protocols and data analysis to extract the weak signal from a dominant background

It was taking as an advice to all and every coronal observatory to analyse the impact of each one of those 4 sources of concern. As a joint project, it was agreed to find and install 2 brightness monitors (SMB's), built for the ATST site survey, in both Pic du Midi and Lomnicky Stit. At least one of those SBM's is known to be at Observatoire de Nice.

A List of Ground Coronagraphs

An (incomplete) list of solar coronagraphs compiled by S. Tomczyk (HAO) follows, including information on claimed scattered light levels.

Instrument	Observatory	Year	Location	Aperture	Organization	Instrument	Occulting	Objective
				(cm)		Scattered Light	Method	Type
Lyot Coronagraph 1	Pic du Midi	1930	Pic du Midi, France	8	Lyot		Internal	Lens
Lyot Coronagraph 2	Pic du Midi	1931	Pic du Midi, France	13	Lyot			
Lyot Coronagraph 3	Pic du Midi	1931	Pic du Midi, France	20	Lyot	5 μB	Internal	Lens
Coronagraph	Arosa	1939	Arosa Station, Switzerland	12	Swiss Fed Obs		Internal	Lens
Coronagraph	Climax Observatory	1940	Climax, Colorado	12	Harvard College Observatory		Internal	Lens
	Kanzelhoe Solar Observatory	1943	Kanzelhohe, Austria	11	IGAM, Graz		Internal	Lens
	Schauinsland Observatory	1943	Schauinsland, Germany	11	Fraunhofer Institute		Internal	Lens
	Wendelstein Solar Observatory	1943	Wendelstein, Germany	11	Univ Obs Munich		Internal	Lens
	Zugspitze	1943	Zugspitze, Germany	11			Internal	Lens
Mk I K-coronameter		1956	Climax, Colorado	8	HAO/NCAR		Internal	Lens
coronagraph	Arosa		Arosa Station, Switzerland	20	Swiss Fed Obs		Internal	Lens
Evans Coronagraph	Sacramento Peak Observatory	1953	Sac Peak, New Mexico	40	NSO		Internal	Lens
Coronagraph		1955	Climax, Colorado	40	HAO/NCAR	30 μB	Internal	Lens
Dual Coronagraph	Lomnicky Stit Obs	1962	Lomnicky Stit, Slovakia	20	Slovak Acad Sci		Internal	Lens
K-coronameter	Zurich		Zurich, Switzerland		Swiss Fed Obs		Internal	Lens
Coronascope II		1964	Baloon	3.2	HAO/NCAR	1.1e-9 @ 1.5 R, 830 nm	External	Lens
	Kislovodsk	1967	Kislovodsk, Russia	53	Pulkovo Observatory	6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Sayan Solar Obs.	1967	Irkutsk, Russia	53		6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Ussuriisk	1967	Ussuriisk, Russia	53		6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Crimea	1967	Nauchny, Ukraine	21	Crimean Astrophysical Obs.		Internal	Lens
	Crimea	1967	Nauchny, Ukraine	53	Crimean Astrophysical Obs.	6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Debrecen	1967	Debrecen, Hungary	53		6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Wroclaw Observatory	1967	Wroclaw, Poland	13	Astronomical Inst Univ Worclaw			Lens
	Bailkow Observatory	1967	Wroclaw, Poland	53	Astronomical Inst Univ Worclaw	6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Batabat	1967	Batabat, Azerbadzan	53		6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Physicotechnical Inst.	1967	Turkmenistan	53		6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Abastumani	1967	Georgia, USSR	53	Abastumani Astrophisical Obs.	6e μB @ 1 arcmin, 546 nm	Internal	Lens
	Alma Ata	1958	Alma Ata, Kazakhstan	53	Kazakh Academy of Sciemce		Internal	Lens
Mk II K-coronameter		1968	Mauna Loa, Hawaii	8	HAO/NCAR		Internal	Lens
Mees 25-cm Coronagraph		1970	Haleakala, Hawaii	25	U of Hawaii		Internal	Lens
	Khureltogot Observatory	1961	Ulan Bator, Mongolia	20	Mongolian Academy of Sciences		Internal	Lens
Coronagraph	Coronagraph	1973	Norikura, Japan	25	Tokyo Ast Obs		Internal	Lens
	Skylab ATM Coronagraph	1973	Skylab	3.2	HAO/NCAR	2E-10	External	Lens
OSO-7 Coronagraph		1975	OSO-7	2.64	NRL	1E-10	External	Lens
	Wendelstein Solar Obs	1975	Wendelstein, Germany	20	Univ Obs Munich		Internal	Lens
P78-1 Coronagraph		1979	P78-1	2.64	NRL	1E-10	External	Lens
SMM Coronagraph		1980	SMM Satellite	2.7	HAO/NCAR	5E-10	External	Lens
Mk III K-coronameter		1980	Mauna Loa, Hawaii	23	HAO/NCAR	7 μB @ 1.15 R, 775 nm	Internal	Lens
One Shot		1980	Sac Peak, New Mexico	20	NSO	3 μB @ 2R,	Internal	Lens
MAC I		1989	Sac Peak, New Mexico	5	NSO		Internal	Mirror
MAC II			Sac Peak, New Mexico	15	NSO		Internal	Mirror
LASCO C1		1995	SOHO	4.7	Max Planck Lindau	15 μB @ 1.1R, 1.e-8 @ 3	Internal	Mirror
LASCO C2		1995	SOHO		NRL	1.00E-11	External	Lens
LASCO C3		1995	SOHO	0.96	NRL	1.00E-12	External	Lens
MICA		1997	El Leoncito, Argentina	4.7	MPIAe	15 μB @ 1.1R, 1.e-8 @ 3	Internal	Mirror

Mk IV K-coronameter		1998	Mauna Loa, Hawaii	23	HAO/NCAR	7 μB @ 1.15 R, 775 nm	Internal	Lens
SOLARC	Mees Solar Observatory	2002	Haleakala, Hawaii	46	U of Hawaii	20 μB @ 1.1 R, 1075 nm	Internal	Mirror
	Bulgaria	2005	Rozhen, Bulgaria	15	National Astronomical Obs.			
Coronagraph			Ondrejov, Czech Republic	13	Ondrejov Observatory		Internal	Lens