Chromospheric and Coronal Magnetic Fields

Thought it would be easy - just comment on good talks

Wow!
So many interesting advances!
Such an exciting set of talks!

European solar physics -- excellent shape
What key points learnt?

**STRUCTURE of Magnetic Field**

1. Photosphere
2. Chromosphere
3. Corona - observations, theory

**DYNAMICS**

4. Coronal Heating
5. Prominences
6. Emerging Flux
7. Eruptive Instability
8. Waves
Life was simple

When we were young / naive

When static,

chrom/tr/corona

-spher\textsuperscript{y} sym\textsuperscript{c}(r)

When $B=0$
Now **loops**, \( B \) everywhere, **Dynamic**
Who said “This is certainly the lousiest talk”? 
Distribution of submission of abstracts as function of time

Guess -- when was the submission date?

But who is this?
“If you’ve heard this before, you can doze for a few minutes”

“There are also problems with dynamo theory - if you have another hour …”
Who said?

“The Sun with no magnetic field would be a star with no spirit”?

Nour-Edine
Who said?

“The good news ..,  The very good news …,  
Is there any bad news?”

“You build a polarimeter, put it into space - it’ll take you 10 years …. but then I will have solved the problem !!”

Javier
Who said?

“Most of us come from flatland”

“God blesses radio astronomers (the anthroporadiomorphic principle)”?

Stephen
Who said?

“I know everything about bald patches”

Thomas
Who said?

“The canopy is like a wineglass”

Andreas
Who said?

“In a dextral filament you are on a highway & going to the exit”

Brigitte
“You can have only 1 final question - I am hungry”

Javier
Who said?

“Our talks in this session are having trouble with the referees”

“I’m not so sure I like kink instability”

Spiro
Who said?

“I am agreeing with Spiro - which is disheartening”

John
Who likes?
“chewy nougat”

Yuhang
Who said?

“The black stuff is just chromospheric junk”

Jorrit
Who could talk or see but not do both?

Cristina
Who said?

“It may be a good idea for me to speak, so that the audience can cool down after Spiro”?

Ineke
“This nice formula didn’t survive translation from laptop to computer”

Alfred
Who said?

“These equations are not meant to destroy your attention”

Joerg
Who sent her family to China for this meeting?

Davina
Who said?

“You may realise the Sun is not an infinite plane”

Sami
1. Structure of Photospheric B

The quiet Sun is *not-so-quiet*

Hector Navarro

[Arturo Lopez]

– Ratio flux in network/cell ?
-- What is intrinsic field strength ? PDF of flux in pixel ?
-- Origin of these fields?
Vertical current in sunspots:
$$\pm 100 \text{ mA/m}^2$$

$$\alpha = \frac{j}{B}$$ varies by factor 100
-- so not linear

Simulations of CO & B in quiet Sun
w. radiative MHD code --> chromo.
very dynamic with filaments
BP’s in $H_{\alpha}$ wing coincide with intergranular B of 1 kG

Gap in flux between G-band bright points & smallest dark pores
? Simultaneous magnetograms
Active regions lose 70% flux by cancellation, 30% can diffuse towards poles.
1.5 Relation Photosphere-Chromosphere

Mei Zhang - Traditional canopy model

too simple

magnetic element in chromosphere not >> photosphere!
Trace loops?

Confinement not a problem
-- ambient B

But puzzled about why Trace loops vertical & constant cross section ???

One possibility -- lie on separatrix surface
Karel Schrijver - review of Magnetic Carpet

- Topologically very complex - reconnects every few minutes.
- Most of **Trace heating** is in small-scale flux in network.
- Corona over quiet Sun is not ff - beta order 1

- Much more **flux in cell** (intranetwork field)!
- **Canopy** - only 30 - 70% of open field ends in network.
- **Intranetwork field** generated by small-scale dynamo --> heats chromosphere
Does a Canopy Exist -- is the concept correct/useful?

What is ratio of network - intranetwork flux?

What is effect of cell flux on canopy?

Need observations/interpretations

In $H_{\alpha}$ - see many horizontal fibrils

If intranet flux small/small-scale, overall canopy preserved

If larger, then disrupt canopy & break through

Whole structure much more complex & dynamic than Gabriel
Origin of fast solar wind in coronal funnels
Cf SUMER doppler shifts w. extrapolated $B$

--->
Funnel area (c. hole) expands by only 10 - not canopy-like
In quiet Sun --> ?? slow solar wind
2. Structure of Chromospheric B

Nour-Eddine Raouafi

Comprehensive review of ways of measuring chromospheric & coronal B
[Zeeman, Hanle, radio, extrapolation]

Hanle with SUMER (O vi 1032 Å) in polar coronal hole at ~1.3 R⊙ --> B=3G

Achim Gandorfer

UV polarimetry from ground is key to chromospheric B  [esp. CaI 4227]
-- reviewed canopy & spicules

B and v in emerging flux region

--> Huge potential of Stokes polarimetry (He 10830)
Very important to compare with models:

Thomas Wiegelmann

**nonlinear force-free fields** give best fit with observed loops
3. Structure of Coronal B

Steve Tomczyk -

Showed how to use coronal emission lines to measure Stokes parameters:
Best lines in infra-red
-- esp Fe XIII

Need a dedicated large (1m) coronagraph
Stephen White - Review radio techniques

For active regions can determine coronal $B > 300$ G.

--> 3D information on B on disc (since optically thick) -- [uses B extrapolations to determine heights]

So complements IR measurements on limb $B < 20$ G
Maxim Kramer

Suggests that coronal Hanle and/or Zeeman data + $\nabla \cdot \mathbf{B} = 0$ can be used to construct non-potential component of coronal $\mathbf{B}$

Javier Trujillo

Masterly case for EUV spectropolarimetry -- using Hanle effect to measure $\mathbf{B}$ in t.r. & corona

Need to put a high-sensitivity UV/EUV polarimeter in space
Thomas Neukirch -

Compared different methods for nonlinear force-free fields -- Wiegelmann optimisation best

In future:
Need better observations (SOLIS, Solar B, SDO)
Need fast and robust methods
Need deal with noise in data and non-force nature of photosphere
Stephane Regnier

Followed evolution of active region [nonlin fff] - Photospheric motions and complex topology are precursors of flaring
Coronal Topology

Pascal Demoulin

1. Model photo of $B$ in terms of discrete flux patches:

Skeleton - set of separatrix surfaces - divide corona

Separatrices intersect in separator - joins null points

Flux transfer occurs by separator reconnection

2. Generalise to continuous field distribution:

Discontinuities in mapping of feet → strong gradients

Separatrix → Quasi-Separatrix Layer

Separator → Quasi-Separator
Some flares occur at separatrices, some at QSL’s

(Mandrini et al, Démoülin et al, Aulanier et al)
Slow footpoint motions in numerical MHD simulation of XBP, j sheet, coronal hole -->

Evolution through piecewise nonlinear fff with current sheets on separatrices/QSLs
4. Coronal Heating

Gene Parker

-- nano/pico-flares -
impulsive recon\textsuperscript{n} in j sheets
from braiding.

-- granules are source energy, waves not effective
Coronal tectonics

-- refinement of Parker-braiding
-- magnetic carpet enhances formation of current sheets

Ineke deMoortel & Klaus Galsgaard:

Twist normal tube -->
weak j.

If feet are in localised
flux patches -->
Separator or quasi-
separator sheets
Hardi Peter

Synthetic spectra from Gudiksen’s 3D numerical experiment on braiding/tectonics

Good match with observed doppler shifts & emission measure

Rekha Jain - model by forced reconnection

Tohri Shimizu - structure of shocks in Petschek recon.
5. Prominences -- for long an enigma

Laura Merenda & Arturo Lopez - measured $B$ in prominences
Nonlinear models for global structure
+ barbs as B-lines ending at parasitic polarity
But Brigitte Schmieder -
Barbs are bald patches [magnetic dips in photosphere]

?? Still puzzled about barbs
Need t-evolution of magnetogram
6. Emerging Flux

Hiroaki Isobe

R-T instability --> filamentation
& fast impulsive bursty reconnection
Etienne Pariat

In EFR, linear fff model -->
Several bald patches as serpentine field lines
-- dips get rid of dense plasma by reconnection
  (Ellerman bombs)

Klaus Galsgaard

  -- flux emerges through
    convection zone
  and reconnects with
  overlying coronal magnetic
  field
Impressive account of structure of large-scale corona

1. Steady polytropic MHD models

?? Effect of better energy eqn (vel\textsuperscript{y} too slow, hole dark)
2. Non-steady models

Differential rotation + t-dependent evolution + -->
Interchange and disconnection reconnection of coronal hole
7. Eruptive Instability (flares & CME’s)

Lyndsay Fletcher

- review of latest results from flare observations

[flare predictions, weak particle acceleration before, problems w. coronal electron acc^n. occurrence of flares in dense medium]

Alexander Nindos

Study of active region evolution

Calculated $H_{rel}$ with linear force-free alpha-best method
Most active regions with large $H_{rel}$ produce CMEs
-- in future nonlinear FFF when fast methods
Emergence of flux rope into a potential arcade

--> CME

Eruption due to magnetic catastrophe when twist > 3.4 $\pi$
Similar model for kink, with different flux tube/overlying field
Spiro Antiochos - breakout model

Filament takes off before flare but ?? timing filament eruption/CME

Need nonpotential B in filament channel, but ?? sheared arcade or twisted loop

Need overlying field, but ?? how does eruption start
Other Suggestions

Bernhard Kliem:

CME’s initiated by **torus instability**
-- don’t need twist in flux tube

Kanya Kusano:

“Reversed shear model” (3D resistive MHD)

$T_{mi}$ --> **sigmoid** as a relaxed linear $$$fff$$$
  -> double reconnection
  -> eruption / flare
So ... ?

All models --> flare loops, but ?? initiation of eruption

?? Several or one mechanism for eruption

Several viable ones now proposed

But which has the essentials ??

Need more realistic initial configurations for num. expts

-- focus on obs\textsuperscript{1} consec\textsuperscript{ces}
Anik de Groof & Daniel Muller

Observations & theory of coronal rain as thermal instability --

Downflow slower than freefall because of compression ahead of blobs

Erwin Verwichte
Tadpole waves - fast magnetacoustic kinks

Cristina Mandrini
Interplanetary clouds - same flux & $H_m$ as erupting a.r.’s
8. Waves

Impressive review of observations/theory of chromospheric waves

- Ca II grains explained by acoustic waves
- 3min waves present already in photosphere
- Non-magnetic chromosphere very dynamic.
- Acoustic waves power factor 10 too small to heat chromosphere

(Fossum & Carlsson, 2005)
Simulation of Magnetic Chromo (2D) Hansteen

- Chromosphere pervaded by waves
- Mode conversions where $C_s = C_a$
Comp\textsuperscript{v}e review coronal oscillations:
In TRACE (transverse global kink)
SUMER (standing slow-mode)
EIT/TRACE (prop\textsuperscript{ng} slow-mode)

More realistic simulations / detailed observations

---> excitation & damping (??)
+ properties corona
i.e. Coronal seismology -- infancy!
Numerical model waves in sunspot:

- Fast-mode refracts back to the photosphere.
- Slow-mode continues up to the chromosphere.

Dipankar Banerjee  Detected long-period magnac.waves in coronal holes at 50 km/s  [wavelet analysis with CDS]

Malgorzata Selwa  Oscillations in a coronal loop
Tom Van Doosselaere  Coronal loop oscillations
Thanassiss Katslyannis  SECIS observations of waves
Claire Foulon  Pulsations in solar flares
SO, what do we have?

A 3D multi-structured coupled dynamic magnetic photosphere, chromosphere & corona on a wide range of scales

for which we need a strong coupling theory-observation & a wide range of talents - to take understanding to new level

In this we can all (as a community) play our part
FINALLY

THANK - Sami Solanki and his merry gang (Andreas, Bernd, Eckart, Manfred, Joerg + Queen Davina)

I HOPE --

We can communicate our sense of vitality to young European scientists of future.