A summary of WG5 (and related) activities:

The Bs Challenge

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The Bs challenge: Statement of the WG
(from ISEST description)

The presence of **southward** magnetic fields in ICMEs are the most important factor in producing **geomagnetic storms**.

The challenge is that **direct observations** of magnetic fields **near the Sun** are **extremely limited**: currently possible only in the photosphere/chromosphere at the solar end and by in-situ observations at 1 AU.

**WG5** aims to **understand and reconstruct** the possible **flux rope magnetic structure** of CMEs/ICMEs from observations and models. It also aims to **predict** the **intensity** and the duration of the **Bs** in ICMEs upon arriving at the Earth.
Direct “diagnostics” of near-Sun & IP CME magnetic fields in the radio domain


**gyrosynchrotron emission** (e.g., Bastian et al. 2001; Tun & Vourlidas 2013)

direct access to CME magnetic fields
(talks by B. Jackson (and CSSS+IPS), I. Cairns, ....)

**Difficult Observations**
Indirect Methods of near-Sun CME B-field Determination

Need robust methods that could be applied on more regular basis

These methods are based on empirical modeling of CME observations
CME-driven shocks

(1) shock stand-off distance from CME/shock WL/EUV observations & WL densities
(2) jump conditions & WL densities

→ $|B|$ in sheath & background

(e.g., Vršnak et al. 2002, Bemporad & Mancuso 2011; Zucca et al. 2014)

Gopalswamy & Yashiro 2011
Bemporad et al. 2015
For LFF cylindrical flux rope (Lundquist 1950):
Dasso, Mandrini, Demoulin et al. 2003 →

\[ B_0 = \sqrt{\frac{2.405 H_m}{4\pi LRJ}} \]

L, R → CME length+ radius from GCS
modeling of CMEs with STEREO (Thernisien et al 2009)

Hm → source-region or eruption-related magnetic helicity from photospheric
magnetic/flow obs & extrapolations
(reviews of methods by Valori et al. 2017; Guo et al. 2017; Pariat et al. 2017;
Georgoulis et al. 2017)

Hm is conserved even with reconnection
(Berger 1985; Pariat et al. 2016)

All input parameters can be determined in a routine base
Extrapolation of near-Sun magnetic field to 1 AU

Use a power-law of the radial distance $r$:

$$B_0(r) = B_\star (r/r_\star)^{\alpha_B}$$

$\alpha_B$-range from Demoulin & Dasso 2009

compilation of observations & models $\rightarrow$ [-2.7, -1.0]

CME b-field
magnitude at 1 AU

Application to a case study

Boxes $\longrightarrow$ model

Horizontal lines $\longrightarrow$ ICME $|B|$

Patsourakos +2016
Parametric Studies of H-CME \textit{(Patsourakos, Geourgoulis 2016,2017)}

Randomly pick up $10^4$ values from the observed AR Hm (Tziotziou et al. 2012) & CME geometrical parameters (Thernisien, Vourlidas & Howard 2009; Bosman et al. 2012) distributions

\textit{Determine near-Sun B* for the $10^4$ synthetic CMEs}

\textit{Extrapolate CME b-field to 1 AU for different $\alpha_B$ for the $10^4$ synthetic CMEs}
Parametric Studies of H-CME

colored --> extrapolated to 1 AU
CME magnetic field

black+white --- outside range of MC observations (Lynch et al. 2003; Lepping et al. 2006)

$\alpha \beta^{-1.6}$ fits reproduces the bulk of MC observations

Extension to various CME models (e.g., non-force-free, spheromac etc)

% of predicted values within the range of MC observations as a function of $\alpha_B$

Robustness of models
Flux rope method

Chen (1989); Kunkel & Chen (2010), Roulliard & Kunkel (2014)

Use observed h-t of a CME to determine its poloidal flux injection profile to match the flux rope kinematics → $B$ at all distances

one case study
Schuck (2011): difficulties with poloidal flux injection in the photosphere
Adequate propagation model
Use GCS fittings (CME width and axis orientation)
→ determine volume of influence of the CME-ICME in the heliosphere
BZ4CAST-cont

Hm sign of source region, axis orientation & impact parameter → Bvec @ 1 AU

applied to 8 events

ENLIL simulations are used to predict the CME magnetic field @ 1AU

red ---> model
FriED (Isavnin 2016)

Generalization of GCS model to deal with CME deformations (skewing, pancaking)

+ Populates GCS with magnetic field structure from LFF
FriED (Isavnin 2016)

flux conservation --->
CME magnetic field @ 1 AU

applied to a case study

Dashes --- model

Uses in-situ observations @ 1 AU to determine near-Sun CME |B|
FIDO (Kay et al. 2017)


magnetic forces acting on CMEs  -->  near-Sun CME deflection + rotation

LFF model + flux conservation  -->  B CME @ 1 AU
FIDO (Kay et al. 2017)

Applied to 4 events

black ----> observations
red ----> model

Uses in-situ observations @ 1 AU for near-Sun |B|
Calculate **reconnected flux** in post-eruption arcades

+ fit **flux rope model** to corresponding CMEs from LASCO observations of 54 CMEs

Apply constraints to Lundquist model --->
CME magnetic fields at 10 Rs (> ambient)
FRED: Coronal and IP attributes  (Gopalswamy et al. 2017)

Good correlation btw Coronal BCME +MC axial field from Marubashi et al. (2015)
Set reference time & define window dt in past
Search 10 years of in-situ data for 50 best dt-long intervals &
use their next dt for forecast
Good match between forecast + observations
Part of the MC should be already observed
Conclusions

No perfect model currently exists

Progress but need to do much more ....
Actions

Test various existing models on the same events

Parametric studies of the various methods

Come up with hybrid schemes + exploit radio + IPS

Collaborate with other WGs (e.g., modeling) for CME rotation

Collaborate with other teams (e.g., International Forum for Space Weather Capabilities Assessment @ CCMC: IMF Bz at L1 Working Team; KSWRS; Euphoria; CESE-AMR; SUNSANOO; ENLIL)
<table>
<thead>
<tr>
<th>Date and Time</th>
<th>Solar Source (AR # or location)</th>
<th>Method of Magnetic Field Determination</th>
<th>Publication</th>
<th>Miscellaneous</th>
<th>Submitter contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011/06/07 06:47 UT</td>
<td>AR NOAA 11226 (CME propagating on the west limb)</td>
<td>The magnetic field in the corona is determined by applying the Rankine-Hugoniot equations to LASCO C2 and C3 white-light images of the CME-driven shock in order to derive a map of the shock Alfvénic Mach number</td>
<td>Bemporad, A. &amp; Mancuso, S. 2010, ApJ 720, 130 (also Bemporad, A., Susino, R., &amp; Mancso, S, ApJ, in preparation)</td>
<td>R. Susino (<a href="mailto:susino@oato.inaf.it">susino@oato.inaf.it</a>) and A. Bemporad (<a href="mailto:bemporad@oato.inaf.it">bemporad@oato.inaf.it</a>)</td>
<td></td>
</tr>
<tr>
<td>2012/03/07 01:14 UT</td>
<td>AR NOAA 11429</td>
<td>The coronal CME magnetic field is estimated by combination of magnetic helicity calculations of the CME source region and forward modeling of the CME along with application of the helicity conservation principle in flux-rope CMEs</td>
<td>Patsourakos, S., Georgoulis, M. K., Vourlidas, A. et al., 2016, ApJ, 817, 14</td>
<td>S. Patsourakos (<a href="mailto:spatsour@cc.uoi.gr">spatsour@cc.uoi.gr</a>)</td>
<td></td>
</tr>
</tbody>
</table>
International Forum for Space Weather Capabilities Assessment @ CCMC: IMF Bz at L1 Working Team

Live workshop updates
- April 2017 working meeting: team agenda | solar/heliosphere agenda | full agenda

- https://igipo.igmabecker.com
- https://igipo.gitlab.com
- https://igipo.gitlab.io
- https://igipo.gitlab.io/IGMB

- Working Team Goals
  - To create a community-agreed selection of events and metrics, that all current and future models should test their magnetic field forecasting capabilities.
  - This will take place in the community to focus on forecasting the magnetic field from the Sun to the Earth. The goal is to achieve consensus on key events and metrics for metrics to be included in the model. The goal is to ensure that the models are validated against events that are representative of the real-world conditions.

- Solicitation for Community Opinions
  - We invite the wider community to participate and provide feedback that will benefit the final determination of evaluation criteria. We will provide specific suggestions on current evaluation frameworks.

- Current list of models incorporated in our discussion:
  - Data driven
    - 1. IMFI model
    - 2. IMF1C model
    - 3. A. Roskill model
    - 4. A. Roskill model (2016)
    - 5. EUROMAG (M. Best) - under development

- Working Team Deliverables
  - Physical Quantities and Metrics for Model Validation
  - Observation Data
  - List of Time Intervals in this Study
  - Return to the Forum Homepage
Most CME $b$-flux is added by reconnection during the eruption.

Lin et al. 2004
Vrsank 2008
Qiu et al. 2004, 2007
Moestl et al. 2009
Hu et al. 2014
Veronig & Polanec 2015

Pre-eruptive $b$-field configuration yields only some hints on the erupting structure $b$-field configuration.
Spectral Imaging of moving metric Type IV radio bursts

Fit observed spectrum with gyrosynchrotron emission spectrum

e.g., Bastian et al. 2001; Tun & Vourlidas 2013

rare observations
Faraday Rotation

Faraday rotation of EM radiation of spacecraft/natural (e.g., pulsar) source through a CME (+ne) $\rightarrow |B|$

e.g., Bird et al. 1985; Jensen & Russel 2008, Kooi et al. 2017

Rare observations

Problems with ionospheric background for ground-based observations

Single LOS issues with CME orientation/handedness (removed by multiple-LOS Liu et al. 2007, Jensen et al. 2010, Xiong et al. 2013)
Benchmarking of Methods

Patsourakos & Georgoulis (2016)  
Gopalswamy et al. (2017)
Work plan

1. Find suitable datasets for near-Sun $|B|$ field calculations applicable to as many of the available methods as possible --- start with events already analyzed by the various team members ---- coordinate w/ the data and campaign WGs (yrs 1-2)

2. Assess the pros & cons of the various methods of near-Sun $|B|$ determination & extrapolation -- coordinate w/ the theory and modeling WGs (yrs 1-2)

3. Apply methods (existing or improved) to a sample of CMEs and determine near-Sun $|B|$ → paper and list of events/data (yrs 2-3)

4. Extrapolate near-Sun $|B|$ & orientation to 1 AU and compare w/ in-situ measurements and MC fittings (Al-Haddad et al. 2013 for a benchmarking of available MC fitting methods) → paper and tables of pertinent data (yrs 3-4)
Predictions for SolO @ 0.5 AU

Predicted CME $|B|$ for $\alpha B = -1.6$ in the inner heliosphere
## Models Recap

<table>
<thead>
<tr>
<th>Model</th>
<th>BZ4CAST</th>
<th>H-CME</th>
<th>HELIO-XM</th>
<th>FIDO</th>
<th>Fried</th>
<th>FRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td>cylinder</td>
<td>cylinder/torus/spheromac</td>
<td>torus</td>
<td>torus</td>
<td>torus</td>
<td>torus</td>
</tr>
<tr>
<td>$</td>
<td>B</td>
<td>$ near-Sun</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>near-Sun deflections</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>IP propagation</td>
<td>radial</td>
<td>radial</td>
<td>radial</td>
<td>radial</td>
<td>radial</td>
<td>radial</td>
</tr>
<tr>
<td>$</td>
<td>B</td>
<td>$ IP evolution</td>
<td>CCMC simulation/Power-law</td>
<td>Force-balance</td>
<td>flux conservation</td>
<td>flux conservation</td>
</tr>
<tr>
<td>B vector</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

*All models have pros and cons*
CME-driven shocks

(1) shock stand-off distance from CME/shock WL/EUV observations & WL densities

(2) jump conditions & WL densities

→ $|B|$ in sheath & background

(e.g., Vrsnak et al. 2002, Bemporad & Mancuso 2011; Zucca et al. 2014)

Gopalswamy & Yashiro 2011

Bemporad et al. 2015
Extracting 3D info of CMES

Forward geometrical modeling: GCS
Thernisien et al. (2009); Bosman et al. 2012 and many case-studies fits the CME envelope & gives CME height, size, direction, tilt not internal structure of CME
Extension to include CME deformations FRiED (Isavnin; 2017)

J-maps
assume CME shape (point, circle, ellipse) + radial propagation → CME speed & direction
(e.g. Sheeley et al. 1999; Roulliard et al. 2011; Lugaz et al. 2010; Mostl et al. 2011, 2014; Rollet et al. 2011, 2016; Davies et al. 2012; Liu et al. 2013)
CME deflections close to the Sun (1.1-20 Rs)

Bosman, Bothmer, Nistico 2012
39 CMEs in 2010
deflections ~ [5,60] deg
towards equator

CME lat offset from SR

Gui et al. 2011
deflection along \( \text{grad}(B^2) \)

deflections \( \rightarrow \) magnetic field gradients
(strong \( \rightarrow \) weak)
Cremades, Bothmer, Tripathi 2006
Gopalswamy et al. 2010
Panasenco et al. 2011
Shen et al. 2011
Kay, Opher, Evans 2013
CME rotations close to Sun 1.1-5 Rs

3D reconstructions of prominence rotations

Thompson, Kliem, Torok 2012

rotations $\sim [30,90]$ deg

Bemporad, Mierla, Tripathi 2011
Joshi & Srivastava 2011
Chifu et al. 2012
Su & van Ballegooijen 2012
Liewer, Panasenco, Hall, 2013
Filippov 2013
Bi et al., 2014
Isavnin, Vourlidas, Kilpua 2013, 2014

15 CMEs 2008-2010
deflection \sim 2-30\,\text{deg}
rotation \sim 2-80\,\text{deg}
60\% \text{ of variation in the first 30 Rs} ;
Most magnetic deflection & rotation due within 10Rs
(Kay et al. 2015)

Interaction of CME with Parker spiral
Wang et al. 2004

Weak CME b-field; how about solar-max CMEs?
Why bothering about CME magnetic fields?

- CMEs are powered by magnetic energy (e.g., Forbes 2000; Vourlidas et al. 2000; Carley et al. 2012; Emslie et al. 2012)


- Magnetic field determines the geoeffectiveness of CMEs (e.g., Burton et al. 1975; O’Brien and McPherron, 2000; Wu & Lepping 2002; Wang et al. 2003)
Future Work

1. Find suitable datasets for near-Sun $|B|$ field calculations applicable to as many of the available methods as possible --- **start with events already analyzed by the various team members** - & populate list @ http://solar.gmu.edu/heliophysics/index.php/List_of_CMEs_for_WG5_Analysis --- compare the predictions of various methods

2. Perform parametric studies of the various methods of CME-ICME magnetic field determination --- assess the full range of anticipated magnetic fields from the various methods

3. Coordinate with other WGs (data/modeling&theory/campaign) as well as with other teams on the topic (e.g., LWS, HELCATS)
People who Expressed Interest

"Alissandrakis Costas, radio diagnostics", ,,
"Bemporad Alessandro, shock-method", ,,
"Bothmer Volker, CME-ICME propagation, MCs", ,,
"Dasso Sergio, theory/modeling of CME expansion and evolution", ,,
"Georgoulis Manolis, helicity method", ,,
"Hess Phill, flux-rope method", ,,
"Isavnin Alexei, CME rotations/deflections mod+obs, MC-fitting", ,,
"Kay Christina, CME rotations/deflections modeling", ,,
"Kilpua Emilia, CME-ICME propagation", ,,
"Maia Dalmiro, radio observations", ,,
"Mancuso Salvatore, radio diagnostics", ,,
"Mierla Marilena", "CME-ICME evolution ", ,,
"Moestl Christian, MC fitting CME-ICME evolution", ,,
"Nindos Alexander helicity method, radio diagnostics", ,,
"Opher Merav, CME rotations/deflections modeling", ,,
"Patsourakos Spiros, helicity method", ,,
"Riley Pete", "CME-ICME evolution, POC with LWS team on Bs", ,,
"Rodriguez Luciano", "CME-ICME evolution Mcs", ,,
"Rouillard Alexis, flux-rope model", ,,
"Savani Neel, CME deformations, shock method", ,,
"Shen Chenglong, MHD modeling of CME rotation/expansion ", ,,
"Shen Fang, MHD modeling of CME rotation/expansion "," POC with WG3", 
"Temmer Manuela, CME-ICME evolution, reconnected flux", "x POC with WG6", 
"Veronig Astrid, CME-ICME evolution, reconnected flux", ,, 
"Vrsnak Bojan, theory of flux-rope model and radio diagnostics", "POC with WG2" 
"Wang Yuming, MHD modeling of CME rotation/expansion ", ,,
"Webb David, POC ", "with WG4",,, 
"Zhang Jie, flux-rope method", ", POC with WG1", ,, 
"Zhukov Andrei", "CME-ICME evolution",,,
Inner heliospheric evolution of ICME-MC $|B|$: Helios 1/2 results

Bothmer and Schwenn 46 MCs (1998); $\alpha_B \sim -1.73$
Forsyth et al. (2006) 103 ICMEs; $\alpha_B \sim -1.31$
Leitner et al. (2007) 46 MCs; $\alpha_B \sim -1.64$

Describe the B evolution of an <ICME>
Few alignment studies (Leitner et al. 2007)
Not comprehensive remote sensing observations
Breakdown of the problem

We need to predict \( B \)s at 1 AU  \( \Rightarrow \) magnitude & orientation of \( B \) at 1 AU

The problem consists of 4 basic steps:

1. **Deduce near-Sun |\( B \)| of CMEs**

2. **Deduce near-Sun orientations of CMEs**

3. **Extrapolate near-Sun |\( B \)| to 1 AU**

4. **Extrapolate near-Sun orientation to 1 AU**
Forecasting of Bn using Pattern Recognition  (Riley et al. 2017)

Use simple pattern recognition applied to OMNI 1-hour cadence data covering 10 years to predict the state of solar wind $\Delta t$ (6 hours – few weeks) into the future

@ time $t$ shift backwards by $\Delta t$ & compare with a sliding window of width $\Delta t$ spanning all the data-base

Find 50 best-matching intervals & use their corresponding next $\Delta t$