Why magnetic helicity?

- Intrinsic property of the physical process
e.g. Inverse MHD cascade, build up of twisted flux rope
- Conserved quantity
  $\implies$ track the magnetic flux from its formation to the heliosphere

Magnetic flux travel

<table>
<thead>
<tr>
<th>Region</th>
<th>Magnetic Field $B$ (G)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heliosphere (1 AU)</td>
<td>$10^{-8}$ T, $10^{-4}$G</td>
<td>expansion, relaxation (MC)</td>
</tr>
<tr>
<td>Corona (low)</td>
<td>$10^{-2}$ T, $10^2$G</td>
<td>accumulation, unstability</td>
</tr>
<tr>
<td>Photosphere</td>
<td>$10^{-1}$ T, $10^3$G</td>
<td>expansion, relaxation transport</td>
</tr>
<tr>
<td>Convective zone</td>
<td>$10$ T, $10^5$G</td>
<td>dynamo, Parker unstability</td>
</tr>
</tbody>
</table>
Magnetic helicity: main features

- Definition of the **relative** magnetic helicity

\[ H_r = \int_V \vec{A} \cdot \vec{B} dV - \int_V \vec{A}_0 \cdot \vec{B}_0 dV \]

with:

\[ \vec{B} = \nabla \times \vec{A}, \]

and, \( \vec{B}_0 \): potential magnetic field.

- **\( H_r \)** is **gauge-invariant** \((\vec{A} \rightarrow \vec{A} + \nabla \Phi)\)

  (Berger & Field 1984, Finn & Antonsen 1985)

- **Conservation** of \( H_r \)

\[ \left| \frac{\Delta H_r}{H_r} \right| \leq \sqrt{\frac{\Delta t}{\tau_d}} \]

with:

\[ \Delta t = \text{evolution time} \]

\[ \tau_d = \frac{L^2}{\eta} \text{(diffusion time)} \]

  (Berger 1984)

- **Hemispherical rules** \((H_r < 0 \text{ in the northern hemisphere})\)

  (Seehafer 1990, Pevtsov et al. 1995, Bothmer & Rust 1997)

- **Accumulation of** \( H_r \) **in the corona** \( \Rightarrow \) **CMEs**

  (Rust 1994, Low 1996)
Input of helicity in ARs

* Magnetic helicity input at the photosphere:

\[
\frac{dH_r}{dt} = \text{helicity flux} \\
+ 2 \int_S (\vec{A}_0 \cdot \vec{B})(\vec{v} \cdot \vec{dS}) \quad \text{emergence} \\
- 2 \int_S (\vec{A}_0 \cdot \vec{v})(\vec{B} \cdot \vec{dS}) \quad \text{differential rotation} \\
+ \quad \text{shearing motions}
\]

(note: can select \( \vec{A}_0 \cdot \vec{dS} = 0 \))

* Evolution of \( B_{ij} \): from SoHO/MDI in AR 7978

* Coronal helicity: from SXT/Yohkoh and lff extrapolation
Input of helicity in two ARs

* Long-term evolution of two ARs:
  - AR 7978: 6 rotations
  - AR 8100: 5 rotations poster: Green et al.
  with: Yohkoh/SXT, SoHO/MDI

* For the two ARs:
  Both differential rotation & shearing motions
  - do NOT bring enough magnetic helicity in the corona
    (up to a factor 10)
  - could be of opposite sign as $\Delta H_{\text{corona}}$

  $\implies$ importance of emergence & torsional Alfvén waves

(Démoulin et al. 2002, Green et al. 2002)
Ejection of magnetic helicity

* How to estimate the magnetic helicity ejected?
  - Identification of all CMEs launched from an AR with: SoHO/(EIT,LASCO)
  - No $\vec{B}$ measurement in CMEs
    $\implies$ Assume: $\langle H_{CME} \rangle = \langle H_{MC} \rangle$
  - In situ measurement of $\vec{B}$ in MCs
    + Model (lfff) $\rightarrow H_{MC}$

* Magnetic helicity in magnetic clouds

\[
\begin{align*}
\log_{10} H_r & \quad \text{deduced from: Lepping et al. 1990} \\
& \quad \text{18 MCs} \\
\log_{10} H_r & \quad \text{Zhao et al. 2001} \\
& \quad \text{23 MCs}
\end{align*}
\]

Assume a MC length $= 0.5$ AU

$\implies \langle H_{MC} \rangle \approx 2 \times 10^{42} \text{ Mx}^2$
Ejection of helicity from two ARs

* Long-term evolution of two ARs:
  - AR 7978: 6 rotations
  - AR 8100: 5 rotations poster: Green et al.
    with: Yohkoh/SXT, SoHO/(MDI,EIT,LASCO)

* Magnetic helicity ejected:

<table>
<thead>
<tr>
<th>AR</th>
<th>$N_{CME}$ observed</th>
<th>$N_{CME}$ corrected</th>
<th>$H_{MC}^{\text{CME obs.}}$</th>
<th>$H_{MC}^{\text{CME cor.}}$</th>
<th>$H_{\text{diff.rot.}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7978</td>
<td>26</td>
<td>31</td>
<td>52.</td>
<td>62.</td>
<td>8.</td>
</tr>
<tr>
<td>8100</td>
<td>19</td>
<td>41</td>
<td>38.</td>
<td>82.</td>
<td>-7.</td>
</tr>
</tbody>
</table>

(in unit of $10^{42} \text{ Mx}^2$)

Note: assume $L_{MC} = 0.5 \text{ AU}$ (only !)

$\implies$ differential rotation do NOT bring enough magnetic helicity!

(Démoulin et al. 2002, Green et al. 2002)

Result $\neq$ DeVore (2000)

difference: sensitivity & duty cycle of the SMM / SoHO coronographs
Input of STEREO

**Photosphere:** Input of magnetic helicity by:
- differential rotation
- shearing motions
- emergence $\Rightarrow \vec{B}$: ASP, THEMIS, SOLAR B

**Corona:**
Determine 3D magnetic configurations: EUVI/SECCHI
\[ (+ \text{ magnetograph}) \]
"loop organisation" $\Rightarrow$ coronal magnetic helicity

**Heliosphere:**
- local measurements of $\vec{B}$ with magnetometer: MAG/IMPACT
  \[ + \text{MC model} \Rightarrow \text{MC magnetic helicity} \]
- "lucky case": detection by STEREO #1 & #2 of the same MC
  \[ \Rightarrow \text{differences in the local properties} \]

**Link Corona-Heliosphere:**
- associate a given MC to a CME:
  coronographs + heliosphere imager of SECCHI
- combine global and local measurements
  with the constraint of magnetic helicity conservation

is a CME the result of coronal helicity build up?