Studying magnetic fields in circumstellar and star forming regions with atomic alignment

Thiem Hoang\textsuperscript{1}, A. Lazarian\textsuperscript{1}, K. Nordseic\textsuperscript{k}, H. Yan\textsuperscript{2}

\textsuperscript{1}UW-Madison, \textsuperscript{2}CITA

**Motivation**
Magnetic fields are essential to understand:
- Star formation.
- Transport of angular momentum in accretion and winds.

**Problem**
Limited ways of directly measuring magnetic fields.

**Approach**
Use of new technique based on polarization arising from absorption and emission by aligned atoms. The theory of such process is described by Yan & Lazarian (2006, 2007). Atomic alignment in a different regime, i.e., strong magnetic field has been used in studies of Solar magnetic field, but not outside the Sun.

**Abstract**
Alignment of atoms and ions with fine and hyperfine structure provides new ways to study magnetic fields in various astrophysical environments. The alignment is induced by radiation, while magnetic field modifies it via Larmor precession. The direction and degree of polarization of absorbed and emitted light provides the information on magnetic field direction. The technique is based on the theoretical studies by Yan & Lazarian (2006, 2007). We discuss observations that can provide unique informations on magnetic fields in circumstellar and star forming regions.

**Instrumentation**
High resolution (R>\(\times\), 10,000) spectropolarimeter

<table>
<thead>
<tr>
<th>Visible:</th>
<th>UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALT, aperture 1m (3200-9000 A)</td>
<td>FUSP, 0.5m (10 50-1450 A)</td>
</tr>
<tr>
<td>NASA sounding rocket (2008)</td>
<td></td>
</tr>
</tbody>
</table>

**Emission lines**
- Orientation of polarization vectors and degree of polarization is a function of magnetic field orientation with respect to observer and the pumping source.
- Several lines can provide 3D direction.

**Examples of emission lines**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Line</th>
<th>Magnetic field</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>(1085.60 \text{ nm} )</td>
<td>1</td>
</tr>
<tr>
<td>b)</td>
<td>(1335.70 \text{ nm} )</td>
<td>1</td>
</tr>
<tr>
<td>c)</td>
<td>(1329.10 \text{ nm} )</td>
<td>1</td>
</tr>
<tr>
<td>d)</td>
<td>(1560.70 \text{ nm} )</td>
<td>1</td>
</tr>
</tbody>
</table>

**Fluorescence in Reflection Nebulae - Visible study**

**Summary**
- Aligned atoms and ions can provide unique information about magnetic field direction.
- Polarization of optical and UV absorption lines can be used for the studies.
- The technique based on atomic alignment can answer most fundamental questions in relation to the physics and the evolution of circumstellar and star forming regions.

**Acknowledgement**
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**References**

**Geometry**
\(\theta_r, \phi_r\): radiation direction about B
\(\theta_s, \phi_s\): direction of line of sight about B
Atoms absorb angular momentum from the pumping source to have differential population on their ground states.

**Observation**
- Position angle: polarization either \(\parallel\) or \(\perp\) to magnetic field B.
- Measuring polarization degree from several lines it is possible to determine 3D direction of B from \(\theta_r, \phi_r\).

**Case: circumstellar region - UV study**
FUV spectrum of alignable lines

**Case: ISM - Visible study**
Orion Veil
TII absorption lines

<table>
<thead>
<tr>
<th>Line</th>
<th>(J_{lower})</th>
<th>(J_{upper})</th>
<th>(P_{obs})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(308.40) nm</td>
<td>(3/2 \rightarrow 1/2)</td>
<td>(0.21)</td>
<td></td>
</tr>
</tbody>
</table>

(Yan & Lazarian 2006)
- Using many lines of sight provide topology of magnetic field.
- Combine with existing Zeeman measurements to give full B.
- Sketch of a thin stellar disk and polarization estimated for toroidal and poloidal magnetic field.
- Combine with MHD model of disk to obtain full B.