Current coming out of SCUBA-2

850a Detector "sees" 5.5 mag earthquake
Magnetic Fields
At Submillimetre Wavelengths

Dr. Steve Mairs (ASTR351L Spring 2019)
Overview

1. Stokes Parameters
2. POL-2 Primer
3. Magnetic Field Science
4. Jellyfish Nebula
Linear Polarisation: The angle of the Electric Field

The POL-2 Instrument at the JCMT is sensitive only to linear polarisation.

The light we receive is only partially polarised - so, from a given part of the sky there is a polarisation angle that has more light oriented in that direction than you would expect from completely unpolarised light.
The Poincaré Sphere and Stokes Parameters

Here’s an opportunity for some math fun! Convince yourself this is true:

\[ S_0 = I \]
\[ S_1 = IP \cos 2\psi \cos 2\chi \]
\[ S_2 = IP \sin 2\psi \cos 2\chi \]
\[ S_3 = IP \sin 2\chi \]

We define the polarisation percentage as:

\[ p = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0} \]

The Stokes Vector \(<l, q, u, v>\)

\[ \vec{S} = \left( \begin{array}{c} S_0 \\ S_1 \\ S_2 \\ S_3 \end{array} \right) = \left( \begin{array}{c} I \\ Q \\ U \\ V \end{array} \right) \]
The Stokes Vector is a convenient way to describe the orientation of polarised light.

\[
\mathbf{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}
\]

Unpolarized

- Linearly polarized (horizontal): \( \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \end{pmatrix} \)
- Linearly polarized (vertical): \( \begin{pmatrix} 1 \\ -1 \\ 0 \\ 0 \end{pmatrix} \)
- Linearly polarized (+45°): \( \begin{pmatrix} 1 \\ 0 \\ -1 \\ 0 \end{pmatrix} \)
- Linearly polarized (−45°): \( \begin{pmatrix} 1 \\ 0 \\ 1 \\ -1 \end{pmatrix} \)
- Right-hand circularly polarized: \( \begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \end{pmatrix} \)
- Left-hand circularly polarized: \( \begin{pmatrix} 1 \\ 0 \\ 0 \\ -1 \end{pmatrix} \)
The Stokes Vector

<table>
<thead>
<tr>
<th>100% Q</th>
<th>100% U</th>
<th>100% V</th>
</tr>
</thead>
<tbody>
<tr>
<td>+Q</td>
<td>+U</td>
<td>+V</td>
</tr>
<tr>
<td>Q &gt; 0; U = 0; V = 0 (a)</td>
<td>Q = 0; U &gt; 0; V = 0 (c)</td>
<td>Q = 0; U = 0; V &gt; 0 (e)</td>
</tr>
<tr>
<td>-Q</td>
<td>-U</td>
<td>-V</td>
</tr>
<tr>
<td>Q &lt; 0; U = 0; V = 0 (b)</td>
<td>Q = 0; U &lt; 0; V = 0 (d)</td>
<td>Q = 0; U = 0; V &lt; 0 (f)</td>
</tr>
</tbody>
</table>
JCMT: Linear Polarisation Only!

\[ S = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} \]

So, for us, the equations get simpler!

V is always 0!

Polarisation Percentage

\[ p = \frac{\sqrt{Q^2 + U^2}}{I} \]

The amount of incoming radiation at the angle defined by Q and U

Polarisation Angle

\[ \text{ANG} = \theta = \frac{1}{2} \arctan \frac{U}{Q} \]

The preferential angle the partially polarised light is landing on the detector
The Radiative Alignment Theory of Dust Grains says:

The long axis of dust grains tend towards an alignment perpendicular to B-field lines.

The polarisation from the light we receive is defined by the dust grain orientation!
POL-2
POL-2: Polarimeter

POL-2 works in conjunction with SCUBA-2. It is not, itself, a detector.

It has 2 Main components:

1. A Rotatable Wave Plate
2. An Analyser
POL-2: Polarimeter

The analyser selects out light coming from a specific polarisation angle and sends that image to the detector.

In order to measure the intensity at multiple polarisation angles, the rotatable plate is introduced to change the orientation of the polarised light before it is sent to the analyser.
By making multiple measurements of the light at different polarisation angles, we can find the maximum and minimum intensity. This is how we derive the polarisation percentage of the light we receive from space and measure its specific, preferred, angle.
Magnetic Field Strength

**Davis-Chandrasekhar-Fermi (DCF) method**
combines POL-2, SCUBA-2, and HARP data to calculate the B-Field strength

\[
B_{\text{pos}} = Q' \sqrt{4\pi \rho} \frac{\sigma_v}{\sigma_\theta} \approx 9.3 \sqrt{n(H_2)} \frac{\Delta v}{\langle \sigma_\theta \rangle} \mu \text{G}
\]


Tracing Magnetic Fields in Space!
What is the overall magnetic field structure?

Do B fields help or hinder star formation?

What are the roles of the filaments and how do they form?

How important are B fields in the dynamics relative to thermal/turbulent energy?
The Jellyfish Nebula

We will be plotting magnetic field vectors and analysing the strength of the field.