B-fields In STar forming Region Observations: BISTRO

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BISTRO: Overview

- Aims to map polarized 850 micron emission towards Gould Belt star-forming regions
- Aims to map the high-column-density regions of: Ophiuchus, Orion A & B, Perseus, Serpens Main, Taurus L1495/B211, Auriga, IC5146
- Awarded 224 hours of Band 2 observing time
- The first science data were successfully taken last night!
- ~100 survey members across 6 partner regions + EAO

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Pol. Image Credit: POL-2 Commissioning Team
Importance of B-field strengths in a Spiral G.

Magnetic fields and spiral arms in M51

|B|-field strength in micro-Gauss

Fletcher et al. 2011
Importance of B-fields in a Spiral G.

Figure 2. Energy densities and their radial variations in the spiral galaxy NGC 6946.

Magnetic fields in the Milky Way and other galaxies have been extensively studied. Energy densities and their radial variations in the spiral galaxy NGC 6946 are shown in the figure.

Field strengths in outer parts of galaxies can be measured by Faraday rotation of polarized background sources. For example, Battaner & Florido (2000) proposed methods for measuring field strengths in outer parts of galaxies. Han et al. (1998) found evidence for regular fields in M 31 at 25 kpc radius, with field strengths similar to those in the inner disk. More detailed studies in a number of galaxies are required.

Magnetic fields seem to play a major and possibly even dominant role in ISM physics, affecting gas flows, cloud collisions and the formation of spiral arms. Strongly tangled fields may provide a source for gas heating by reconnection.

5. Large-scale field structures

The Sun is located between two spiral arms, the Sagittarius/Carina and the Perseus arms. The mean pitch angle of the spiral arms is $\approx -18^\circ$ for the stars and $-13^\circ \pm 1^\circ$ for all gas components (Vallée 1995, 2002). Starlight polarization and pulsar $RM$ data give a significantly smaller pitch angle ($-8^\circ \pm 1^\circ$) for the local magnetic field (Heiles 1996, Han & Qiao 1994, Indrani & Deshpande 1998, Han et al. 1999a). The local field may form a magnetic arm located between two optical arms, with a smaller pitch angle.

For external galaxies, maps of the total radio emission and ISO maps of the mid-infrared dust emission reveal a surprisingly close connection (Frick et al. 2001b, Walsh et al. 2002). Strongest total fields generally coincide with highest emission from dust and gas in the spiral arms. This suggests a coupling of the tangled magnetic field to the warm dust mixed with cool gas. The regular field runs parallel to the spiral arms, though its ridge line is generally offset and, in some galaxies, forms magnetic spiral arms between the gaseous arms (Fig. 3) or across the arms, like in NGC 3627 (Soida et al. 2001).

6. Star Formation

6.1. Energy density

The energy density can be calculated using the following equations:

- Magnetic field energy density: $E_{\text{mag}} = \frac{|B|^2}{8\pi}$
- Turbulence energy density: $E_{\text{tur}} = \frac{1}{2} \rho v^2$
- Ionized gas energy density: $E_{\text{ion}} = \frac{3}{2} n_e kT$
- Neutral gas energy density: $E_{\text{neut}} = \frac{3}{2} n_H kT$
- Cosmic ray energy density: $E_{\text{c.r.}} = C \int E^{-2\alpha} dE$

Beck, R., 2004
Filaments, Cores, and Protostars: Hierarchical Structure

Column density map derived from 70 – 500 μm maps taken with Herschel

Aquila Rift — Active SF

Polaris — Quiescence

A surface density threshold for star formation? \( M_L \sim \Sigma \times H \)

where \( M_L \) critical line–mass, \( \Sigma \) denotes surface density, and \( H \) scale height.

Andre et al. 2010; see also Palla and Stahler 02, Goldsmith+08, MeMen’shchikov+08
Filament evolution and Core Formation: Regulated by $B$ field?

Overall Taurus: **Molecular line**

B213 in Taurus: **Dust Cont.**

Goldsmith et al. 2008

Palmeirim et al. 2013

Super critical filament $\perp$ Magnetic field

Subcritical filament $\parallel$ Magnetic field
Need to explore B-fields in high-density gas

“AKARI” surface density map, YK and RSF in prep
Furuya et al. 2014 with Poidevin & Bastien 2006 (NIR pol) and RSF+08 (cores)
POL-2 + SCUBA-2: Unique tool

- **Only** open-instruments in the northern sky
- Tracing pol. structure in **high-density** gas of $n(\text{H}_2) \sim 10^{3-5}$ cm$^{-3}$, while Opt/NIR pol. does $\sim 10^{1-3}$ cm$^{-3}$
- 14” beam @850 um:
  - **Links arcmin-scale** by e.g., Planck with *(sub)arcsec-scale* by ALMA, SMA, NOEMA
  - Corresponding to $\sim 1700$AU@120 pc — **Core-scale down to envelope-scale**
  - Comparable with the Nobeyama 45m beam@3mm
To obtain maps of polarization position angle and fractional polarization in a statistically meaningful sample of cores.

To characterize the evidence for and relevance of the field and turbulence (in conjunction with previous and follow-up HARP-B/FOREST observations) in cores and their surrounding environments.

To test the predictions of low-mass star formation theories (filament, cores, outflow, field geometry), and grain alignment theories.

To generate a large sample of objects that are suitable for follow-up with other instruments, such as ALMA, SMA, Zeeman measurements at Nobeyama 45m.
POL-2: the Instrument

A single-beam imaging polarimeter

Measures linear polarisation (Stokes Q & U)

Half-wave plate (2Hz rotation)

Fixed analysers

Credit: POLPACK documentation/SUN 233

Credit: POL-2 User Manual
POL-2: Current Status

- **Final stages** of commissioning → “Science run” : the first data were taken last night!

- Basic **instrumental polarization** (IP) well-established: 1.3%, parallel to elevation axis, at 850µm

- Details of instrumental polarization model being investigated: Dependence on elevation
  Variation across the focal plane

- Revised flux conversion factors: ×1.35 at 850µm; ×1.96 at 450µm

- **Tiling** of observations to map larger regions currently under investigation
POL-2: Performance

Credit: POL-2 Commissioning Team
POL-2: Comparison with SCUPOL

Credit: POL-2 Commissioning Team
Finalized “Single Field” at BISTRO survey:

- A “field” is 3-arcmin radius with a DAISY scan mode
- $\sigma \sim 2$ mJy/14” beam with PFOV= 12” using 850 um filter @ $\tau_{225} \sim 0.07$ (weather band#2)
- Completed by 14 hrs observing time

- Awarded time 224 hrs / 14 hrs per field = 16 fields can be observed
- ~100 members in consortium / 16 fields ~ 6.25 members per field
- Japan, Korea and UK ~ 20 members each $\rightarrow$ 3 fields per country
- Canada, China and Taiwan ~ 12 members each $\rightarrow$ 2 fields each
BISTRO: Project Status and Plan

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Ophiuchus: 3 fields in L1688 and L1689
Auriga: 1 field
Taurus: 2 fields in the B211/213 filament, 1 field in L1495
Perseus: 2 fields in NGC1333, 1 fields in B1
Serpens: 2 fields in Serpens Main
Orion: 1 field in Ori-A (commissioning field), 1 in Ori-B
IC5146: 1 field

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- Management team (six PIs, Observatory, POL-2 team) meets once per month via Skype. PIs liaise with their own communities.
BISTRO: Publication Plans

- Started to write “consortium” paper towards the “commissioning field” Orion A by Derek Ward-Thompson with Commissioning Team

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- **First-generation publications**: 16 papers by mid-2017
  - Will focus on presentation of POL-2 data
  - Will be written by 6 “geographic regions” towards the 16 assigned “astronomical regions”
  - All members will appear in all first-generation publications

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- **Second-generation publications**: >8 papers, after mid-2017
  - Will statistically discuss scientific topics across SF-regions
  - Will be written by one or more “geographic regions”
Team BISTRO-J:

held **ALMA Workshop** “B-fields in SF-regions and ISMs” on March 30 & 31: 37 participants including 24 non-BISTRO members
pursues scientific discussion towards the 1st generation papers
• “B-field In Star forming Region Observations” started!

• We expect to observe many molecular clouds to an unprecedented depth in polarized emission at 850 micron (<2 mJy/14” beam).

• This will enable determination of magnetic field direction and strength in dense star-forming gas.

• POL-2 is a completely unique instrument, and we intend to make the most of it to answer some of the most pressing questions in star formation.

• 19 members in “Team BISTRO Japan” are intensively working on DR, dust alignment mechanism, numeral simulations, and we are challenging crowd-funding for trips to JCMT