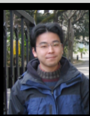
Distortion of Magnetic Fields in a Prestellar Core



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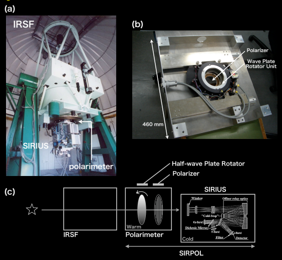
Magnetic fields are believed to play an important role in controlling the stability and contraction of molecular cloud cores. In the present study, magnetic field of a cold prestellar core, Barnard 68, has been mapped based on wide-field near-infrared polarimetric observations of background stars. A distinct "hourglass-shaped" magnetic field is identified toward the core, as the first observational evidence of magnetic field structure distorted by the gravitationally contracting medium in a prestellar core. Our findings on the geometry of magnetic fields as well as the mass-to-magnetic flux ratio are presented.

IRSF/SIRPOL - A Wide-field NIR Polarimeter



(a) IRSF 1.4 m telescope equipped with SIRIUS camera in South Africa.
(b) Newly developed polarimeter unit (half-wave plate rotator & polarizer).
(c) A schematic illustration of IRSF/SIRPOL.

Performance of IRSF/SIRPOL

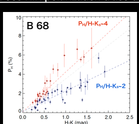
- JHKs-simultaneous imaging polarimetry (Linear pol.)
- Field of View : 7.7′ × 7.7′ (1k×1kx3, 0.45 ″/pixel)
- Band: J (1.25 μm), H (1.63 μm), Ks (2.14 μm)
- Sensitivity (for point sources):
  J = 19.2, H = 18.6, Ks = 17.3 mag
  (S/N = 5, 15 min exp. at 4 wave plate angles)
- Observation Efficiency:
  100 min for the default mode observations
  (10 sec × 4 wave plate angle × 10 dither × 9 set)
- Accuracy of P measurements:
  $\delta P < 1$ % : J < 16.5, H < 15.7, Ks < 14.5 mag
- Accuracy of PA measurements: δPA < 3 degree
- Polarization Efficiency:
  95.5 % (J), 96.3 % (H), and 98.5 % (Ks)
- Shortest Exposure Time: 1.6 sec
- Site Information:
  Sutherland, South African Astronomical Observatory.
  Typical Seeing: 1-1.5″ @J band, Altitude = 1760 m.

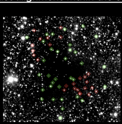
(See, Kandori et al. 2006, Proc. SPIE, 6269, 159)

Making use of the wide-field capability of IRSF/SIRPOL, we are conducting the search of young stars with circumstellar structure, i.e., with large polarization produced by dust scattering. They will be target stars for the extensive survey of exoplanets and disks using Subaru telescope.

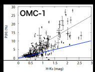
Polarization (P_H) versus Color (H-Ks)

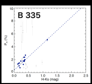
--- Does NIR polarization trace the dust alignment within the core?

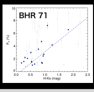


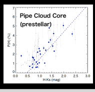


- ✳ P_H linearly increases with increasing H-Ks. The polarization from the densest core region can successfully be traced, at least up to Av ~ 20 mag.
- ✳ There are "two components" in the H-Ks vs P_H diagram. The distributions of data points in each component are spatially separated as shown in the right figure. The orientations of (distorted) magnetic field lines pervading the core may cause the separation of data points.
- ✳ Similar relationships ($P_H \propto$ Color) have been found in massive SFRs (OMC-1/ Kusakabe+08, NGC 2024/Kandori+07, etc..) as well as other dense cores (B 335, BHR 71, a prestellar core in Pipe nebula), confirming our result that NIR polarization traces B-fields inside dense cloud interior.



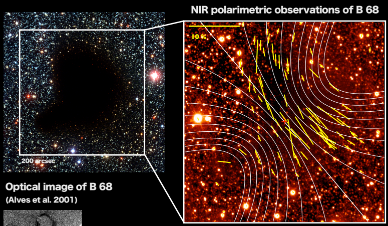




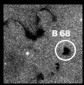


Magnetic Field Studies of a Prestellar Core with SIRPOL

--- Barnard 68: a well-defined starless globule in Ophiuchus.



Optical image of B 68
(Alves et al. 2001)



H band (1.6μm) polarization vectors of background stars (125 stars) superposed on the intensity image at H. The white lines show the magnetic field configuration inferred from the fitting using a parabolic function.

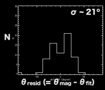
Fitting B-field lines

The most probable geometry of magnetic field lines is estimated using a parabolic function.

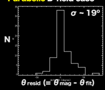
The best-fit parameters are θ_{mag} ~ 40° and C ~ 2x10^{-4} arcsec^{-2} for the parabolic function $y = g + gCx^2$, where g specifies magnetic field lines, θ_{mag} denotes the position angle of magnetic field direction, x denotes the distance from magnetic axis, and C determines the degree of curvature in the function.

The following figures show the histograms of the residual of observed θ_{mag} after subtracting the fitted angle θ_{fit}.

Uniform B-field case



Parabolic B-field case



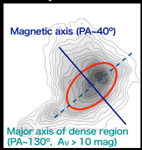
The parabolic fitting seems successful, because dispersion in residual angle is smaller in the parabolic case.

Physical Properties of B 68

- Distance : ~100 pc
  - * Value drived using "equilibrium" assumption.
- Radius : ~10000 AU
- Mass : ~1 M_{solar}
- Temperature(T_{kin}) : ~11 K
- Turbulent linewidth (FWHM) :
  ~0.21 km s^{-1} (N_2H^+ J=1-0)
- H_2 column density : 2.6 x 10^{22} cm^{-2}
- Density structure
  - * Density contrast (ρ_c/ρ_s) : ~16
  - * Well fitted with nearly critical Bonnor-Ebert sphere (marginally stable configuration)

References
- Alves et al. (2001), Hotzel et al. (2002), Lada et al. (2003), Lai et al. (2003)

Geometry of B 68



Rotational axis of the core could be in ~0° to ~20° (PA). (Lada et al. 2003)

Magnetic Properties of Barnard 68

Chandrasekhar-Fermi Method: Assuming that the magnetic field is frozen into the medium, the the intrinsic dispersion in the magnetic field direction, $\Delta\theta_{int} = (\Delta\theta_{resid}^2 - \mathrm{obserror}^2)^{1/2}$, can be attributed to the Alfven wave perturbed by turbulence.
The strength of the plane-of-sky magnetic field can be estimated from

$$B_{POS} = C_{corr}\,(4\pi\rho)^{1/2}\,\sigma_{turb}\,/\,\Delta\theta_{int}$$

- C_{corr} is a correction factor suggested by theories. We adopted C_{corr} = 0.5 (Ostriker et al. 2001)
- ρ: mean density (~1.4x10^{-19} g cc^{-1}), σ_{turb}: turbulent velocity dispersion (~0.09 km s^{-1})
- $\Delta\theta_{int}$: polarization angle dispersion (~17.5°)

A relatively weak magnetic field is obtained as a lower limit of total strength |B|: B_{POS} ~ 20 μG
(A similar value can be obtained [~21 μG], if we assume equipartition between turbulent and magnetic energy.)

Evaluating Magnetic Support against Gravity: The ratio of mass-to-magnetic flux to a critical value suggested by theory (Nakano & Nakamura 1978; Tomisaka, Ikeuchi, & Nakamura 1988), $\lambda = (M/\Phi)_{obs} / (M/\Phi)_{critical}$, can be used to evaluate the ability of magnetic field to support the core against gravity.
λ ~ 2.3 (magnetically supercritical) was obtained in the present case.

Physical Status of Barnard 68

- The (possible) mother cloud that formed B 68 core seems already dissipated, because we find few extinction/polarization toward the outside the core.
  - ✳ Thus, the core would maintain the balance with ISM pressure after the disappearance of surrounding medium, if the core is stable.
- Though our findings show that magnetic fields could not support B 68 against gravity, this does not necessarily mean the gravitational collapse. It was suggested that the core is marginally stable with the support from thermal and (small) turbulent pressure. The relatively weak magnetic fields can act as an additional support to retain B 68 to be stable.
  - ✳ The oscillating gas motions (no signature of gas infall) observed toward B 68 also support the stable configuration (Lada et al. 2003).
- The "hourglass-shaped" magnetic field structure discovered toward a stable core B 68 can be interpreted as an imprint of mass condensation (by gravitational contraction and/or turbulent compression) in the development of the core.
  - ✳ The orientation of the elongated structure in the core is perpendicular to the magnetic axis. The geometrical relation supports the picture of mass accretion along magnetic field lines, as suggested by theories.

Magnetic Properties of B 68

- Magnetic field lines follow a distinct not linear axisimmetric shape (like an "hourglass"), which can be well fitted by a parabolic function.
  - Observational evidence of gravitational distortion of magnetic field lines.
- Magnetic field direction: ~40° (PA)
  - Perpendicular to the direction of core's elongation axis (PA~130°).
- Dispersion in polarization angle after subtracting the fitted angle: ~17.5°
- Magnetic field strength (P.O.S.): ~20 μG
- Mass-to-magnetic flux ratio: ~2.3
  - Magnetically supercritical

☆Those who are interested in using our instruments are welcome to propose service/attendant observations for future collaborative studies.
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