SPICA Meeting in 2017 (ISAS/JAXA, 22Nov. 2017)

Observations of disks around young stellar objects

Recent progresses and Prospects of polarization observations with SPICA

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~ 0.1pc

wa,

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B-field

8. M. (2 9. M. 0. T an an A The Astrophysical Journal, 846:122 (21pp), 2017 September 10 Pattle et al. (Palmeirim+ 2013; Heyer+ 2008) 0 \overline{a} **he**
dica \mathcal{V} ed
R F **D** Taurus@250μm + Optical/IR Pol.

(1) Polarization observations of Protoplanetary & Debris Disks

Polarization in a protoplanetary disk A new window opened by ALMA

theoretical background

Origin of dust polarization at mm-submm

- 1. Thermal emission of "aligned" grains (Tazaki+ 2017)
	- Two alignment mechanisms
		- A. *J II B* : Larmor precession (*B*: magnetic field)
		- B. *JIK*: Radiative precession (*k*: net radiation flux)
	- Radiative alignment (*J II k*) seems dominant for a large grains (*a* > 100μm) in a protoplanetary disk
- 2. Self-scattering of anisotropic radiation fields by dust grains (Kataoka+ 2015, 2016a; Yang+ 2016)
	- High albedo, *and,* High pol. efficiency are required [←] prominent only at λ~ (2π)amax ; strong λ-dependence !

Two external alignment mechanisms

Various timescales of related processes in a protoplanetary disk *(Tazaki et al. 2017)*

Timescale : the shorter is more important

theoretical background Origin of dust polarization at mm-submm

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- Two alignment mechanisms
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HL Tau: Strong λ-dependence *Kataoka et al. (2017, 2015); Stephans et al. (2017; 2014)* the ALMA observations of HD 142527 (Kataoka et al., 142527 (Kataoka et al., 142527 (Kataoka et al., 142527 (Ka observations are too coarse to resolve more than a few $\frac{1}{2}$ independent beams across the disk, making it disk, m to distinguish bet and (2017, 2018) $-$ the $+$ Dbservations

Polarization directions suggests and the their long axes per percent with the set of the s

aligned with the magnetic field. However, except for magnetic field. However, except for magnetic field.

- ^λ=3.1mm: azimuthal ← radiative alignment (i.e., *J ‖ k*) lar to the λ =3.1mm: azimuthal \pm \mathbf{F} $\mathbf{$ Kataoka et al. 2017), 1.3 mm (middle), and 870 *µ*m (bottom),
- $\lambda = 0.87$ mm: parallel to the minor axis \leftarrow self-scattering \bullet $\lambda = 0.87$ mm: parallel to where the red vectors show the *>*3 polarization morphology (i.e., minor axis \leftarrow selt-scattering. $\qquad \qquad$ tional to *P*. The color scale shows the polarized intensity, which is
	- consistent with the case of *a*max [≈] 100μm with *n*(*a*) [∝] *^a*-3.5 \bullet consistent with the cas ⁰⁰4 resolution, Kataoka et al. 2017) suggest that the \mathbf{r} and \mathbf{r} and \mathbf{r} in each panel \mathbf{r} contours in each panel pa T a_{max} ≈ TUUµm With *n*(a) ∝ a^{-5.5} *^I* is 44, 154, and 460 *µ*Jy bm¹ for 3 mm, 1.3 mm, and 870 *µ*m,

Protoplanetary Disks/Debris Disks with SPICA/SAFARI

- \bullet protoplanetary disks are very bright at λ =160µm ■ 89.1 Jy (HL Tau) & 4.1 Jy (TW Hya) : "filled" T Tauri disks ■ 1.9 Jy (V1094 Sco) & 1.8 Jy (Sz 91) : "transitional" disks
- will not be able to spatially resolve them...
	- **Polarization will be detected only when the polarization** directions in the disk are rather uniform
	- λ-dependence of polarization detection scattering? (Kataoka-san's talk)
- can detect & resolve POL in nearby debris disks β Pic, Fomalhaut, ε Eri, Vega : "The Fabulous Four" п τ Cet : 120 mJy at λ =170μm (ISO) r_{out} = 52au at d=3.65 pc Alignment mechanism, constraint on dust size, etc.

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(2) The role of magnetic fields in protostellar phase : disk formation, outflow ejection

…

Magnetic braking catastrophe? *Li et al. (2011); see also Machida et al. (2014)* <u>I' SAA AISO MACDIOZ</u> 10¹⁸ $\frac{1}{\sqrt{2}}$ 1 $\frac{1}{2}$

MHD simulation including Ohmic dissipation & Ambipolar diffusion, *B II Angular Momentum (AM)*, sink cell = 6.7au No disk forms due to very efficient removal of AM **Figure 3. Absolute 3.** Absolute values of the computed magnetic diffusivities for the intervalues for the interval s dl TVI 10⁴ 10⁶ 10⁸ 10¹⁰ 10¹² rem 1
1012 zu relation given in Equation (5). For the MRN case, the MRN case, the Hall diffusivity $\mathsf{D}\mathsf{V}$ in $\mathsf{D}\mathsf{V}$ in

Figure 4. Density distribution (color map) and velocity field (white arrows) of the reference model (Model REF) in the meridian (left panel) and equatorial (right panel) planes, at a representative time $t = 6 \times 10^{12}$ s. The highly flattened, dense equatorial structure is not a rotationally supported disk, but rather a magnetically supported, nearly non-rotating pseudodisk. Also plotted in the left panel are poloidal field lines, with the same magnetic flux between adjacent lines. The color bars above the panels are for $log(\rho)$, with g cm⁻³ and cm as the units for ρ and length.

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CARMA Survey of Protostars in Perseus *Tobin et al. (2015)* observations

 \circ

 -1

 -1

 -0.5

 -0.5

continuum

There ARE protostars accompanied by circumstellar disks

2 having r >100au disk (L1448 IRS2; Per-emb-14)

3 marginally resolved (L1448 IRS3B, I03282, L1448C)

3D-Simulation including Hall current *Tsukamoto et al. (2015)*

• non-ideal MHD (Ohmic dissipation, Ambipolar diffusion & Hall current) • Initial configuration of *AM* & *B* in core-scales affects the disk evolution

ALM Journal ALM is a strong supplement ALM is a strong series, 2013 ALM **1.3mm Survey of Dust Polarization by CARMA** *Hull et al. (2014); "TADPOL"-survey* ast Foldhization by **v** redshifted/blueshifted lobes of the molecular outflow, probably driven by IRAS 4B (*8*), solid lines show the $\frac{m_{\rm max} - m_{\rm max} - m_{\rm max}}{2}$

- Pol. towards 30 cores and 8 regions forming stars at 2.5" Contour map of the 877 µm dust emission (Stokes I) including low-mass Class 0 & I **Red Vectors: Length is proportional to the strategy of the strategy of the strategy**
- Compare with \approx 20" B-fields with JCMT etc. as well as small-scale outflow directions **Example 10.5** Right Ascension (J2000)

c.f.) B-vectors derived from λ=877μm Pol. with SMA(red); Girart et al. (2006)

1.3mm Survey of Dust Polarization by CARMA Hull et al. (2014); "TADPOL"-survey

1.3mm Survey of Dust Polarization by CARMA *Hull et al. (2014); "TADPOL"-survey*

(Results)

- A subset of objects (high pol.) have consistent B-directions in both size scales, but others do not.
- Outflows seem randomly aligned with B-fields at least for high-P_{frac} sources
- **• B-directions (small & large) • Outflows**
- **• AM (the axis of rotating disk)** *are not always parallel*

interferometer. The comparison of polarization angles should be

Recent progress (1): New large-scale maps *Ward-Thompson+ (2017); Pattle+ (2017); "BISTRO"-team*

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- JCMT + SCUBA-2/POL-2, $14"$ -beam at λ =850 μ m λ λ =000 μ m Poi. mage $H_{\rm eff}$ for this work we use P for half-vector selection on ly, so P for α
- B \perp filament vs. B || filament $\overline{\mathsf{m}}$ the relative values $\overline{\mathsf{m}}$ and $\overline{\mathsf{m}}$ and $\overline{\mathsf{m}}$
- B-field strength estimated by Chandrasekhar-Fermi method 3. Results
- equipartition of energy between B-field & turbulence and measureiipartition of energy between erd & turbulence the magnetic field by

turbulent and other motions in the gas.

We determine the plane-of-sky magnetic field strength stren $\sqrt{n_{\rm H_2} \Delta v_{\rm turb}}$ in \sim $B_{\rm{pos}} \propto \frac{V}{V}$ $\langle \sigma_{\theta} \rangle$ and $\langle \sigma_{\theta} \rangle$ $\sqrt{v_{\theta}}$ *s* $\sqrt{6}$ *m* $\frac{1}{2}$ $\frac{1}{$ **q** $q \rightarrow q$ $q \rightarrow q$

a systematic method to derive <σθ> is also employed and *a* (Hildebrand+2009; Pattle+ 2017) *istemand memod to derive* \sim 13 disc cripicy calls the typical deviation is the typical deviation in \sim density of molecular hydrogen (*r* = *m*m H H 2 *n*(), where μ is the

parameter). Crutcher et al. (2004) take *Q*¢ = 0.5 (see Ostriker

B-field map in Orion based on λ=850μm Pol. image

Recent progress (2): ALMA Pol. maps *Hull+ (2017)*

Recent progress (2): ALMA Pol. maps *Hull+ (2017)*

the cores shown in the bottom row. The full simulation boxes are 5.2 pc in extent (cloud scale). The middle row shows zoom-ins between JCMT and CARMA scales

Nearby Star-forming regions with SPICA/SAFARI

- B-field structure in size-scale ≳ dense cores
	- **n** change of field directions in smaller size-scales (ALMA)…
		- statistics on protostellar disks
		- outflows' structure
	- **n** field strengths
		- Chandrasekhar-Fermi method
		- Other methods (e.g., Koch+ 2012)
		- need cross-check with Zeeman?
- **•** vs. Submm Single Dishes wavelength dependence
	- dust characterization,

- alignment mechanism (environmental effects, etc.)

misalignment between B & AM may produce **Two types of outflows ? (Matsumoto+ 2017)** as of outflows 2 (Matermate , 2017)

is misaligned with the circumstellar disk. Similarly, the flattened envelope may be misaligned with the circum-

4. The internal distribution of angular momentum in the cloud cores is nonuniform. After long-term evolution, the disk accretes lumps of gas in which the direction of the angular momentum vectors is highly nonuniform; hence, the disk is expected to change its orientation and size. This means that a planet formed during a later phase may have an orbital angular momentum that is highly misaligned with the angular momentum of the cen-

5. A strong magnetic field tends to produce a cavity in the infalling envelope; this is due to the strong magnetic pressure, and the gas accumulates on the rim. Thus, the rim can account for the arc-like structure and dense gas condensation observed in the high-density molecular cloud core MC27/L1521F, though it has not been verified by observation that there is a high contrast between the column density of the cavity and that of

We would like to thank K. Tokuda, T. Onishi, K. Tomida, R. Kawabe, and N. Ohashi for fruitful discussions. Numerical

Measurement of the Disk Radius

Figure 15. Schematic diagram of two types of outflows: (a) magnetocentrifugal wind, and (b) spiral flow. The surfaces represent isodensity surfaces, and the tubes denote the magnetic field lines. The arrows indicate the direction of the outflow.

λ-dependence infalling envelope, and bipolar outflows are ejected. The nonmagnetized models produce massive circumstellar

λ~350μm (Gandilo+ 2016; Fissel+ 2016) BLAST observations in Vela C molecular clouds (red) do not show "polarization-minimum" at disks, one of which undergoes fragmentation at ∠104 minutes fragmentation at ∠104 minutes fragmentation at ∠104 rvations in Vela (; mo 2. The radius of the circumstellar disk dependence on the initial disk dependence on the initial disk of the i
The initial disk dependence on the initial disk dependence on the initial disk of the initial disk of the initi t snow "polarization-minin m (Gandilo+ 2016: Fissel+ \mathcal{L} mass to stellar mass computations were carried out on the Cray XC30 and XT4 at the Center for Computational Astrophysics, National Astronouao _{Iapa} $\begin{array}{ccc} \text{c.1} & \text{c.1} & \text{c.1} \\ \text{c.1} & \text{c.1} & \text{c.1} \\ \text{d.2} & \text{d.3} & \text{d.4} \\ \text{d.5} & \text{d.7} & \text{d.8} \end{array}$ The University of Tokyo. The University of Toky \mathbf{b} 26400233, 26287030, 25400232, 24244017, 23540270, and \cdot \cdot \cdot

Summary

Small-scale structure of polarization in protoplanetary disks has been detected by ALMA self-scattering and alignment (next talk)

- Nearby debris disks will be important targets for SPICA/SAFARI
	- **dust characterization**
	- **most of them are difficult to detect pol. even by ALMA**

Large vs. small scale B-fields and their connection with disk/outflow structure and their evolution ■ B-Field's directions & strengths at various size-scales wavelength dependence of polarization efficiency