

# Toolbox

Below are resources for the White Paper

The web page of “EAO sub Futures” meeting held in the last month,

<https://www.eaobservatory.org/jcmt/science/futures-2019/>

You can check talk slides at

<https://www.eaobservatory.org/jcmt/science/futures-2019/eao-sub-mm-futures-program/>

The wiki front page:

<https://www.eao.hawaii.edu/EAO-Futures-Discussion-2019/>

The wiki for Magnetic fields:

<https://www.eao.hawaii.edu/EAO-Futures-Discussion-2019/White%20Paper%20Magnetic%20Field>

The 850micron MKID camera details:

<https://www.eao.hawaii.edu/EAO-Futures-Discussion-2019/Continuum%20Discussion?action=AttachFile&do=view&target=Guide-to-the-new-850um-MKID-camera-performance.pdf>

Link to the overleaf document for the WP:

<https://www.overleaf.com/read/btjgvvsmfph>

All the notes in a red box were added  
by R.S.Furuya after the meeting.

# EAO-JCMT new camera B-field WP Working Group

June 19, 2019, GMT 01:00 — 03:00

Present:

Shih Ping Lai , Woojin Kwon, Archana Soam ,Tie Liu ,  
Sarah Sadavoy, Hiroko Shinnaga, Tao Chung Ching,  
Eswaraiah Chakali, Nagayoshi Ohashi, Naomi Hirano, Di Li,  
Rei Enokiya, Harriet Parsons, Ray Furuya

# Agenda

We can follow this agenda:

(0) welcome (~5 min)

(1) share the proposed capability of the new camera (by Harriet; ~10 min).

(2) share the goal and the mission of the WP (by Harriet; ~5 min).

(3) discuss an outline of the B-field portion of the WP (a half hour or more)

- 3a. a proposal from myself
- 3b. introductions of ideas so far proposed ( a few min x n persons)

(4) share tasks and confirm timelines of tasks

(5) other business

# Today's goal

- To share scientific ideas, and to agree overall direction(s)
- To determine structure of the WP
- To assign tasks



# Members

(sorry for the incomplete information)

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| 2.Derek WardThompson  | 17."peterscycluna@asiaa.sinica.edu.tw" |
| 3.Pierre Bastien      | 18.Nagayoshi Ohashi                    |
| 4.Shih Ping Lai       | 19.Jongsoo Kim                         |
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| 6.Woojin Kwon         | 21."liutiepku@gmail.com"               |
| 7.Kate Pattle         | 22. Kazuhiro Hada                      |
| 8.Steven Mairs        | 23.Zhiwei Chen                         |
| 9.Archana Soam        | 24.Naomi Hirano                        |
| 10.Shuichiro Inutsuka | 25.Di Li                               |
| 11.Tie Liu            | 26.Jinjin Xie                          |
| 12.Simon Coudé        | 27.Tatsuya Takekoshi                   |
| 13.Sarah Sadavoy      | 28.Rei Enokiya                         |
| 14.Hiroko Shinnaga    | 29.Ray S. Furuya                       |
| 15.Tao Chung Ching    |                                        |

# Members : **BISTRO** members

(sorry for the incomplete or possibly wrong identification)

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| 13.Sarah Sadavoy      | 28.Rei Enokiya                         |
| 14.Hiroko Shinnaga    | 29.Ray S. Furuya                       |
| 15.Tao Chung Ching    |                                        |

# Members : SMA/ALMA/VLBI experts

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# Members : **SOFIA experts**

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# Members : **opt/NIR polarimetry experts**

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# Members : experience of Zeeman, GK effects

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# Members : who can cover non-ISM&SF

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- |                       |                                        |
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| 13.Sarah Sadavoy      | 28.Rei Enokiya                         |
| 14.Hiroko Shinnaga    | 29.Ray S. Furuya                       |
| 15.Tao Chung Ching    |                                        |

# Members : instrumentation, EAO, project manager

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27. Tatsuya Takekoshi
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# Members : theory, simulation

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18.Namachi Obuchi

**We discussed whether or not we should invite people who can cover fields that cannot be covered by us. e.g., only one theorist.**

**This will be judged accordingly during the writing process.**

23.Zhiwei Chen

24.Naomi Hirano

25.Di Li

26.Jinjin Xie

27.Tatsuya Takekoshi

28.Rei Enokiya

29.Ray S. Furuya

## 1. Role of B-fields in the progenitors of massive stellar clusters

- Owing to the rapid evolution, farther distance, and heavy extinction, studies of massive stars remain elusive. In addition, emergence of luminous massive young stellar objects (MYSOs), ultra compact HII regions, and strong stellar winds and outflows, from massive O/B-type stars would disrupt and leaving no clues on the preexisting physical conditions.

- Infrared quiet massive clumps at an early evolutionary phase are excellent laboratories to unravel and study the primordial physical conditions such as B-fields and turbulence (Csengeri et al. 2017a). Recent ALMA observations of these sources revealed that most of the clumps remain less fragmented and that the core masses largely exceed thermal Jeans mass (Csengeri et al. 2017a,b) requiring additional support from B-fields and/or turbulence. *Measuring B-field strengths and morphology will shed light on the role of B-fields in these targets.*

With the upcoming new 850 $\mu$ m camera with polarimeter having the better sensitivity and faster scanning speed, it is now possible for us to observe these faint and distant massive infrared quiet massive clumps.

## 2. B-fields in isolated dark globules

- Dark globules are the potential sites for the low-mass star formation. Being isolated from the star-forming regions and having simple structures, these targets would offer us to investigate the pristine conditions on physical conditions. Turbulence in these targets is found to be sub-or trans-Alfvénic (eg., Heyer et al. 2008; Franco et al. 2010) and the cores embedded in them are found to be characterized by subsonic turbulence (Myers & Benson 1983; Goodman et al. 1998). These results imply that turbulence is inadequate to counteract the gravitational collapse. In addition, there is no general consensus on whether low-mass star formation is driven by turbulence or B-fields, or both.

- Previous sub-mm polarization observations, using SCUBA-POL, were conducted only towards a few limited sample (Matthews et al 2009); and also that these observations have often been revealed only a few vectors thereby providing limited information on B-fields. This is partly because of the limited sensitivity (also poor dust grain alignment and complex B-fields at the denser parts). With the new camera, we will be able to observe the faint dark globules in order to shed light on whether the low-mass star formation is driven by turbulence or B-fields.

## 3. Other points

- It is essential to probe B-fields in the extended emission around the low-mass cores (eg., Taurus/B213). This would allow us to test whether B-fields aligned parallel to the filament axis at the denser parts of the filament, due to gravitational or turbulent compression, and/or reorientation of oblique shocks in magnetized colliding flows (eg., Fogerty et al., 2017).
- Synergies with other upcoming polarimeters such as SPICA-POL (B-BOP; André et al. 2019). B-BOP aims to probe the B-fields at the wavelengths, scales, and densities similar to those observed by *Herschel* space mission.
- Fast scanning speed would result less systematic uncertainties and hence better results on B-fields? Because, fainter targets observed for longer time will produce significantly larger number of sets. If these observations acquired at slightly different weather conditions, the final results would be effected in comparison to those set of observations acquired for lesser time? (I am not sure about this but curious to know the answer!)

## References

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## Suggestions for “SCUBA-3” magnetic fields white paper

Proposed science goals for the next decade of science at the James Clerk Maxwell Telescope (JCMT):

1. **The evolution of magnetic fields from the scale of filaments to that of protostellar cores.** In general, dust grains are expected to align their long-axis perpendicularly to magnetic field lines in the interstellar medium through Radiative Alignment Torques (e.g., Andersson et al., 2015). This alignment leads to a preferential polarization of the dust thermal emission, thus allowing submillimeter polarimetry to be an effective probe of magnetic field structures in star-forming regions.

With its current and future polarimetric capabilities at  $850\ \mu\text{m}$ , the JCMT is perfectly suited to characterize the plane-of-sky component of magnetic field structures in the densest, coldest regions of the interstellar medium. Specifically, the BISTRO survey using POL-2 has reliably provided some of the most detailed maps of magnetic field structures in nearby star-forming regions (e.g., Ward-Thompson et al., 2017). We now have a more complete picture of the relationship between magnetic field structure in filaments, hub-filaments, and protostellar cores (e.g., Wang et al., 2019; Coudé et al., 2019).

Expanding the scope of the BISTRO survey to include higher-mass star-forming regions, or additional fields near previously observed regions, will provide a more varied sample of magnetic field morphologies in a wider range of environments. With improved detector sensitivity, it will be possible to characterize the field structure both towards fainter regions (e.g., prestellar cores) or even farther star-forming regions in our own Galaxy. Additionally, higher sensitivity will improve the detection rate towards dense cores showing significant depolarization effects, such as is currently seen in several BISTRO regions.

2. **The magnetic and turbulent properties of star-forming regions.** A central contribution of submillimeter polarimetry is to provide measurements of magnetic field amplitudes in star-forming regions through the Davis-Chandrasekhar-Fermi (DCF) technique (Davis, 1951; Chandrasekhar & Fermi, 1953; Crutcher et al., 2004). This method was developed further by Hildebrand et al. (2009), Houde et al. (2009), and Pattle et al. (2017) in order to mitigate the effect of large-scale variations on the derived magnetic field strengths.

In particular, the Angular Dispersion Function (ADF) developed by Houde et al. (2009) was successfully tested on at least three regions (Coudé et al., 2019; Liu et al., 2019; Wang et al., 2019). This method can recover information about the turbulent correlation length of magnetized turbulent cells in star-forming regions, as well as the turbulent-to-ordered magnetic field ratio. An on-going investigation of the BISTRO survey is to extensively test the different DCF methods.

Indeed, with more varied star-forming environments to study or more sensitive detectors recovering more polarization vectors, it will be possible to put strong constraints on the results provided by the currently used DCF techniques. This will establish the regimes in which these DCF techniques can be used reliably.

3. **A multi-wavelength probe of magnetic field structures in molecular clouds.** Polarimetric observations at  $450\ \mu\text{m}$  can complement  $850\ \mu\text{m}$  data by probing potentially different dust populations at higher resolutions. This could serve as a valuable probe of changing field morphologies along the line-of-sight towards dense regions with large temperature gradients (e.g., the BN/KL

object in Orion A). Indeed, observations with the Stratospheric Observatory for Infrared Astronomy (SOFIA) have already shown that apparent variations of field orientation can be observed at different wavelengths (Chuss et al., 2019).

4. **The characteristics of magnetic fields in extra-galactic environments.** Submillimeter polarimetry, like in dusty galaxies such as Messier 51 or Messier 82. These observations would complement our understanding of the relationship between galactic-scale and cloud-scale magnetic fields.

Additionally, polarimetry at  $850\ \mu\text{m}$  allows the study of magnetic fields and turbulence in highly ionized media with strong synchrotron emission such as jets launched by active galactic nuclei (AGN). Specifically, temporal monitoring of AGN with jets is a useful tool to characterize magnetized turbulence near their central supermassive black holes (e.g., Jorstad et al., 2007; Marscher, 2014). More sensitive detectors would allow us to monitor fainter objects significantly faster than is currently possible, which would allow for more frequent monitoring and thus more robust periodograms.

5. **The alignment efficiency of interstellar dust grains with magnetic fields.** Precise measurements of the polarization fraction  $P$  in varying interstellar environments is a probe of the alignment efficiency of dust grains with ambient magnetic fields (e.g., Andersson et al., 2015). While indirectly related to the study of magnetic fields, testing grain alignment mechanisms is essential to confirm that we are indeed properly interpreting the magnetic properties of star-forming regions in our Galaxy.

## Bibliography

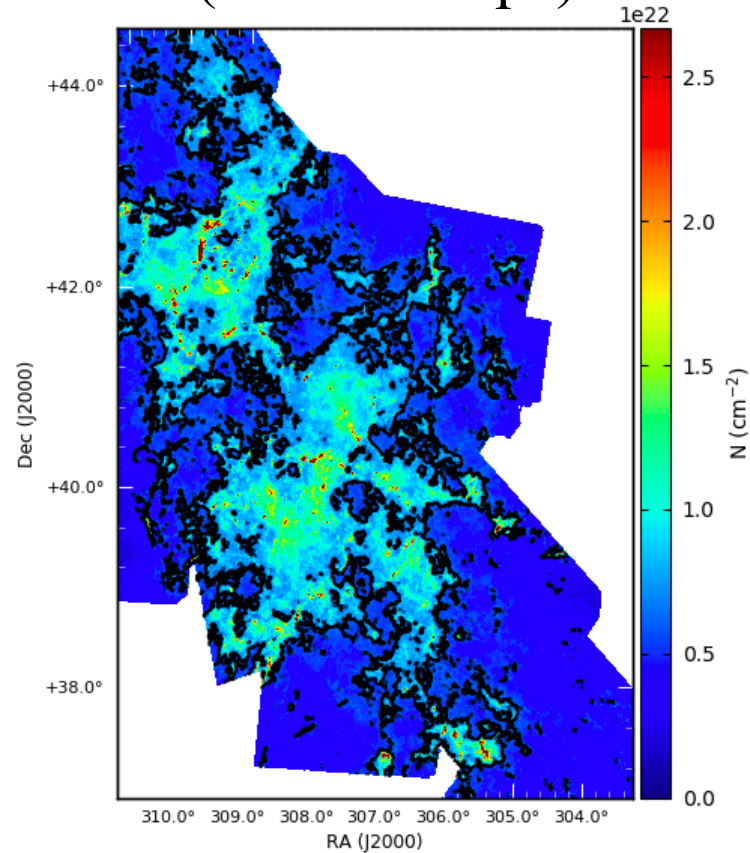
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- Ward-Thompson, D., Pattle, K., Bastien, P., et al. 2017, *ApJ*, 842, 66

# Dust polarization survey of star-forming gas in a giant molecular cloud

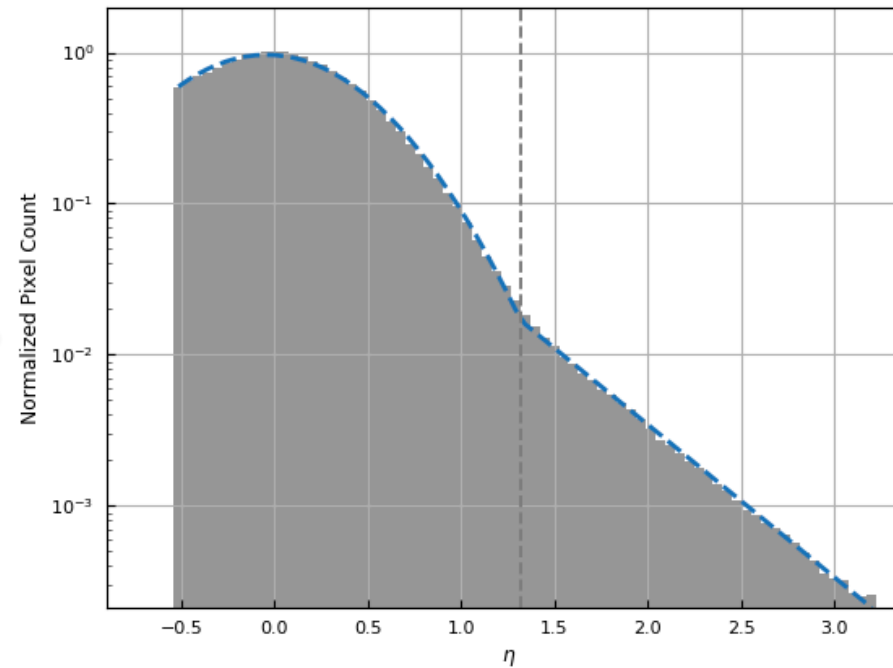
**Keping Qiu (Nanjing University)**

- **First complete survey of dust polarization in star-forming gas within a GMC**
- **The connection of magnetic fields between spiral arms, GMC (from Planck), and star-forming clumps/cores?**
- **How is the alignment between magnetic fields and star-forming clumps/cores affected by environments?**
- **The role of magnetic fields in clump/core formation, evolution, and in the efficiency/rate of star formation?**

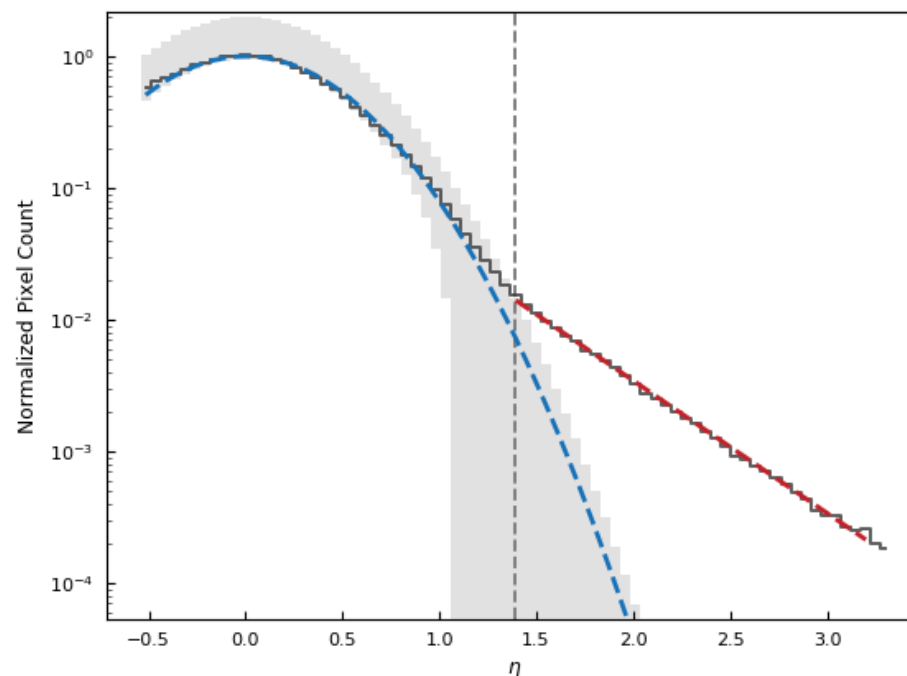
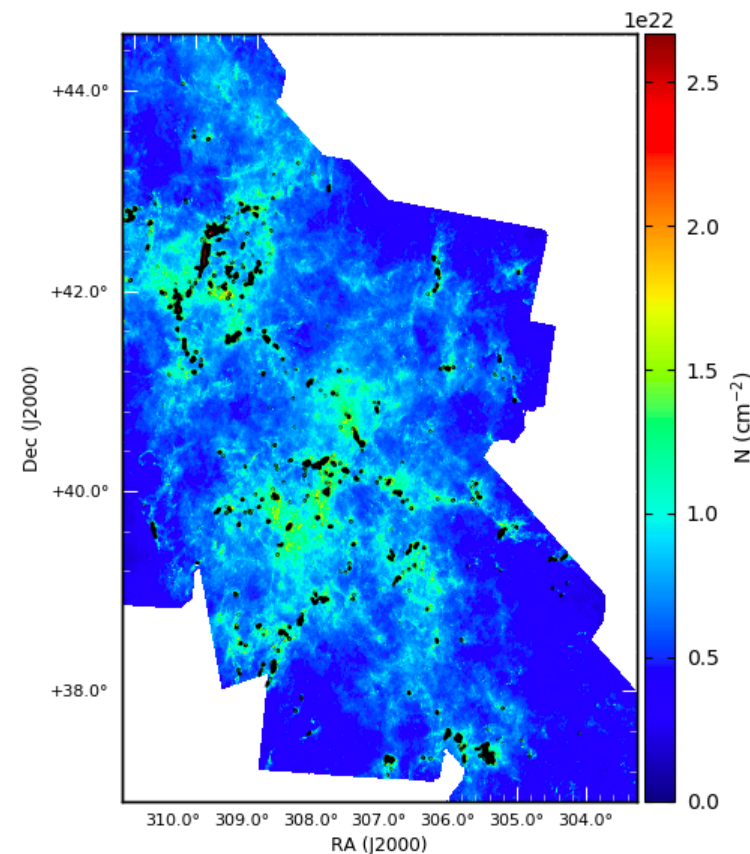
$N(\text{H}_2)$  map of Cygnus-X  
(size > 100 pc)



PDF of  $N(\text{H}_2)$



The area of all the star-forming gas in Cygnus-X, an extremely rich and massive GMC, measures  $\sim 600 \text{ arcmin}^2$ .



Using the new MKID camera, a polarization survey of the star-forming gas with rms reaching 2 mJy can be done with <100 hours!

## Infos for the “BISTRO” WP with the new 850 $\mu$ m Camera

Here are some relevant extracts from the McMaster University internal proposal which has been recently approved by the University. An improved version of this proposal should eventually be submitted to the Canada Foundation for Innovation. I contributed a significant part of the text, together with Steve Mairs and A-Ran Lyo. The text has been edited and corrected by Christine Wilson (Canadian PI of the proposal) to fit with the rest of the proposal. I assume we can use it, but ideally, we should “paraphrase” it.

### **McMaster internal proposal**

#### **Section 3b, past realizations:**

BISTRO science covered: “morphology of the magnetic fields relative to filamentary structures (Pattle et al. 2018) and using the Davis-Chandrasekhar-Fermi method (e.g. Houde et al. 2009) to measure the strength of the magnetic field (Pattle et al. 2017).”

#### **Section 4b. Describe your overall vision, research themes, and specific objectives**

“Magnetic fields play a key role in shaping star-forming structures and in the energy balance in star-forming gas. The BISTRO survey is mapping the magnetic field structure in the densest regions of the Gould Belt, which includes most nearby star-forming regions. It is also observing some of the best-studied regions of high-mass star formation, which lie at somewhat larger distances from the Sun. Even for the most distant regions, about 6000 light years away, the JCMT still has sufficient angular resolution (14 arcseconds) to resolve the same filamentary structures that we see in our closest regions. Herschel observations have shown that all filaments in the nearby regions appear to have approximately the same width of 0.3 light years (e.g. Arzoumanian et al. 2011), while more massive regions have either the same or larger filament widths (e.g. Schisano et al. 2014). The intermediate scale provided by the JCMT is ideal for testing models of star formation. The current model (André et al 2014) has a cloud first break into filaments and then material flows onto it along striations perpendicular to the filaments (Palmerin et al. 2013). But we want to know what happens *inside* the filaments themselves.

With the polarimetric capabilities of the new camera on the JCMT, we will gain the ability to map magnetic field morphologies across entire star-forming regions. Because magnetic fields are inherently multi-scale structures, interpretation of the magnetic fields in the high-density filaments and clumps mapped by BISTRO is difficult without the broader context of the magnetic field in the cloud of gas in which these structures are embedded. With the new camera, we can increase the sample from the 32 clouds in BISTRO to more than 600 clouds for a similar amount of telescope time. With the increased sensitivity, we would also be able to observe polarized submillimeter emission from fainter regions in molecular clouds. Crucially, this would allow us to make a direct comparison of the submillimeter polarization with extinction polarization data from



optical telescopes and thus obtain quantitative results to test theories of how dust grains align along magnetic fields.

With complete maps of a large sample of both nearby and massive star-forming clouds, we will have an unmatched data set that will allow statistical comparison of the magnetic field properties across a range of environments. This data set will allow us to trace how lower density gas connects to the filaments and inwards to the dense regions that form individual stars. These maps of the magnetic field morphology will allow us to connect between super-high resolution images achievable with ALMA with the relatively low resolution all-sky map from the Planck survey. This data set will also provide new information on the magnetic boundary conditions for star formation, which will be used to produce better theoretical models of magnetic fields using the novel methods and software tools being developed by Dr. Fiege (Manitoba) and his graduate students."

**4d. Describe what has already been, or is currently being, done in the research area at McMaster, within the region, within Canada, and internationally.**

"**The BISTRO survey** (Bastien, Mairs, and Lyo) is mapping the magnetic field morphology in the densest regions of the nearest star-forming clouds in our own Galaxy. This survey aims to determine the relative importance of magnetic fields in the star formation process and to test current models of star formation, including magnetic funnelling of material onto filaments. Nearly two-thirds of the data collection is complete, but much work remains to be done for the data processing, analysis, and dissemination of the results." (as of January 2019)

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**Examples of what can be done with a new BISTRO survey with 500 hours with the new 850 $\mu$ m camera on the JCMT.**

Since Stokes parameters Q and U are typically only a few percent of Stokes I, significantly more telescope time is needed to reach the same sensitivity in polarized intensity. However the gain in scientific information it provides is only starting now to become really appreciated.

The goal for BISTRO was to reach 1.3 mJy/beam in each field. However, in 14 hours total time per field, the ITC gives a RMS value of 1.51 mJy/beam for a source at 40 deg. declination in band 2 weather with a 12 arcsec pixel size.

- 1) Same depth, 1.5 mJy per beam (14 hours with POL-2/SCUBA-2)

With POL-2 and SCUBA-2, the central area of uniform sensitivity is 3 arcmin in radius and decreases to zero at about 11 arcmin from the centre. Assuming a useful radius of 7 arcmin yields an area of 154 arcmin<sup>2</sup> per POL-2 CV Daisy field. BISTRO made 16 such observations in 224 hours for 2 460 arcmin<sup>2</sup>. Converting to 500 hours total time (as opposed to integration time) we get an area of 5 500 arcmin<sup>2</sup> or 1.5 deg<sup>2</sup>.

With the new Camera in polarimetry mode, the mapping speed will be increased by a factor of 20 in polarimetry mode (according to the Guide provided by EAO), therefore an area of 110 000 arcmin<sup>2</sup> or 30.5 deg<sup>2</sup> will be obtained during the same 500 hours. For comparison, the area expected to be covered by the original Gould belt survey with HARP and POL-2 for extended regions was only 0.08 deg<sup>2</sup> (Ward-Thompson et al. 2007) or 380 times smaller. \*\*\* This should be updated with the real area values finally obtained by the GBS with SCUBA-2 and HARP.\*\*\* The area 30.5 deg<sup>2</sup> corresponds to the deep survey areas listed in Table 1 by Ward-Thompson et al. 2007 for all these regions: Orion, Taurus, Auriga, Perseus, IC 5146 and Ophiuchus. Most of them were observed in part with POL-2 for BISTRO-1 and -2. Note that Orion makes 14.4 deg<sup>2</sup> by itself.

2) Same area covered, with sensitivity improvement by a factor of 20 (for polarimetry)

With the same conditions, a source at 40 deg. declination in band 2 weather with a 12 arcsec pixel size, one reaches a RMS sensitivity of 0.34 mJy/beam with a 12 arcsec pixel size. This would give a 1- $\sigma$  uncertainty of 0.1% for a 340 mJy source, assuming the IP can be characterised with this precision, or 0.5% for a 68 mJy source, or 1.0% for a 34 mJy source, all of these assuming the source is polarized at 1.0%.

3) Of course, we will most likely work between these two extremes, with a larger area than with POL-2 and with a better sensitivity.

One of our goals is to map to lower density regions so that we can compare with optical extinction maps by having more extended regions with overlap between submm and visible data. So, for a future BISTRO survey with the new Camera, we will have to choose a “goal” sensitivity-depth for our new survey.

Pierre Bastien  
2019-06-14

**Re: Re:REMINDER --- Re: Magnetic fields white paper (JCMT new camera): a telecon**

Peter Scicluna <peterscicluna@asiaa.sinica.edu.tw>

2019/06/19 (水) 9:36

宛先: Ray S. FURUYA <rsf@tokushima-u.ac.jp>; kate.m.pattle@gmail.com <kate.m.pattle@gmail.com>

Dear Ray and Kate,

Firstly, I apologise for not being able to make it to today's telecon. I have not had the time to prepare properly.

Secondly, I hoped we could discuss the question of polarisation in evolved stars somewhat. I'm leading the evolved-stars WP, and we intend to include a section on polarisation and B fields in AGB stars and PNe. As it appears you also have that in mind, it would probably be good to make sure both WPs are consistent on that topic.

Such observations with SCUBA-2 have been nearly impossible - we have an approved proposal for CW Leo (the brightest AGB star at 850), and we need roughly 30 hours to map polarisation on a reasonable scale. Observing any other sources looks like it would only be feasible with the new camera. We're interested in this not only as a probe of the large-scale magnetic field, but also to study grain properties.

It would be good to discuss this further. What do you think?

Cheers,

On Wed, 19 Jun 2019, 07:32 Ray S. FURUYA, <[rsf@tokushima-u.ac.jp](mailto:rsf@tokushima-u.ac.jp)> wrote:

Dear All,

Please find the attached PDF for the materials of today's discussion.

Ciao

Ray

""""

Ray S. FURUYA, Associate Professor, Ph.D.

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Minami Jousanjima-machi 1-1, Tokushima, Tokushima 770-8502, Japan

Phone = +81-88-656-8016 (office), +81-90-2826-1961 (cell), +81 is the

country code, email = [rsf@tokushima-u.ac.jp](mailto:rsf@tokushima-u.ac.jp), skype ID = rsfuruya

# 1 Science goals

## 1.1 Magnetic fields in the ISM

With the polarimetric capabilities of the new instrument, the JCMT will gain the ability to map magnetic field morphologies across entire molecular clouds. POL-2 is currently unique among single-dish instruments in its ability to map individual dense clumps and cores at  $< 15$ -arcsec resolution (e.g. Ward-Thompson et al. 2017). However, as magnetic fields are inherently multi-scale, like the interstellar medium through which they are threaded, interpretation of the magnetic behaviour of an individual clump is difficult without the wider context of the magnetic field in the cloud in which it is embedded. This new instrument, with a FOV equal to the current maximum extent of a POL-2 observation, would provide this context for star-forming clumps, while also providing detailed information on the magnetic field behaviour in the lower-density environment of the surrounding molecular cloud at the same resolution. This would provide vital evidence in the ongoing debate over whether stars form in a magnetically super- or sub-critical environment, and on whether the evolution of molecular clouds is magnetically mediated (e.g Crutcher 2012).

## 1.2 Polarization properties of supernova remnants and planetary nebulae

Although the vast majority of observations performed with both SCUPOL and POL-2 have been of star-forming environments, there are other extended sources in which polarization properties may be studied, particularly supernova remnants and planetary nebulae. ALMA observations of the environments of evolved AGB stars show complex structure in the outer layers shed by the stars (Maercker et al. 2012). However, observing such faint objects in submillimetre polarization is currently prohibitively time-consuming. SCUPOL observed only two supernova remnants, the Crab Nebula and Cassiopeia A, and marginally detected two planetary nebulae, NGC 6302 and NGC 7027 (Matthews et al. 2009). Of these, only the Crab Nebula has thus far been observed with POL-2 [check this]. With the  $10 - 20\times$  increase in mapping speed of this instrument over POL-2, polarization observations of nearby planetary nebulae and supernova remnants at  $850\mu\text{m}$  will be achievable, opening a new field of study for the JCMT.

## 1.3 Polarization variability

As part of POL-2 commissioning work, the commissioning team monitored the quasars 3C273 and 3C84 over a period of months (Coudé et al., in prep.). With the new instrument, such studies could be expanded upon and systemized, to make time monitoring of polarized extragalactic sources routine. The JCMT Transients Survey has demonstrated that observing variable submillimetre sources in nearby molecular clouds with the JCMT is practical (e.g. Johnstone et al. 2018); with this instrument, variability studies could be performed in polarized light.

## 1.4 Dust grain properties

Dust grain properties can be investigated through examination of the polarization spectrum in the mm/smm (e.g. Gandilo et al. 2016; Guillet et al. 2018). This camera will provide measurements at  $850\mu\text{m}$ , a wavelength not covered by any other single-dish instrument in polarized light. Through synthesis with the HAWC+, BLAST-TNG and LMT Toltec instruments (all with resolutions in the range  $5-50$  arcsec), a well-sampled polarization spectrum from  $50 - 2200\mu\text{m}$  could be constructed for many molecular cloud environments.

This instrument, by observing at  $850\mu\text{m}$ , will sample the coldest dust in molecular clouds, and will observe further up the spectral energy distribution than LMT/Toltec. This difference in brightness, as well as the altitude of the JCMT, will counteract the poorer atmospheric transmission at  $850\mu\text{m}$  than

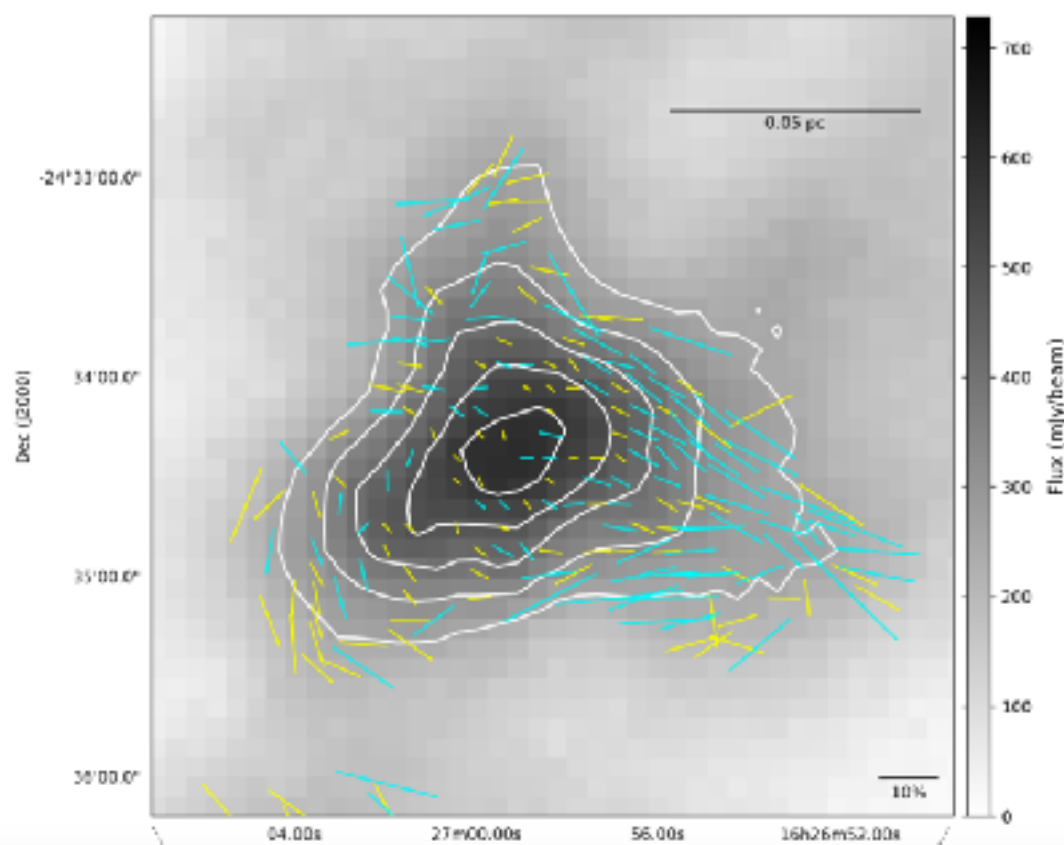
in the millimetre regime. Additionally, by observing at  $850\mu\text{m}$ , this instrument's observations will not be subject to the synchrotron effects which may affect longer wavelengths, other than potentially in the most extreme environments (Rumble et al. 2015).

Crutcher 2012, ARA&A 50 29  
Gandilo et al. 2016, ApJ 824 84  
Guillet et al. 2018, A&A 610 A16  
Johnstone et al. 2018, ApJ 854 31  
Maercker et al. 2012, Nature 490 232  
Matthews et al. 2009, ApJS 182 143  
Rumble et al. 2015, MNRAS 448 1551  
Ward-Thompson et al. 2017, ApJ 842 66

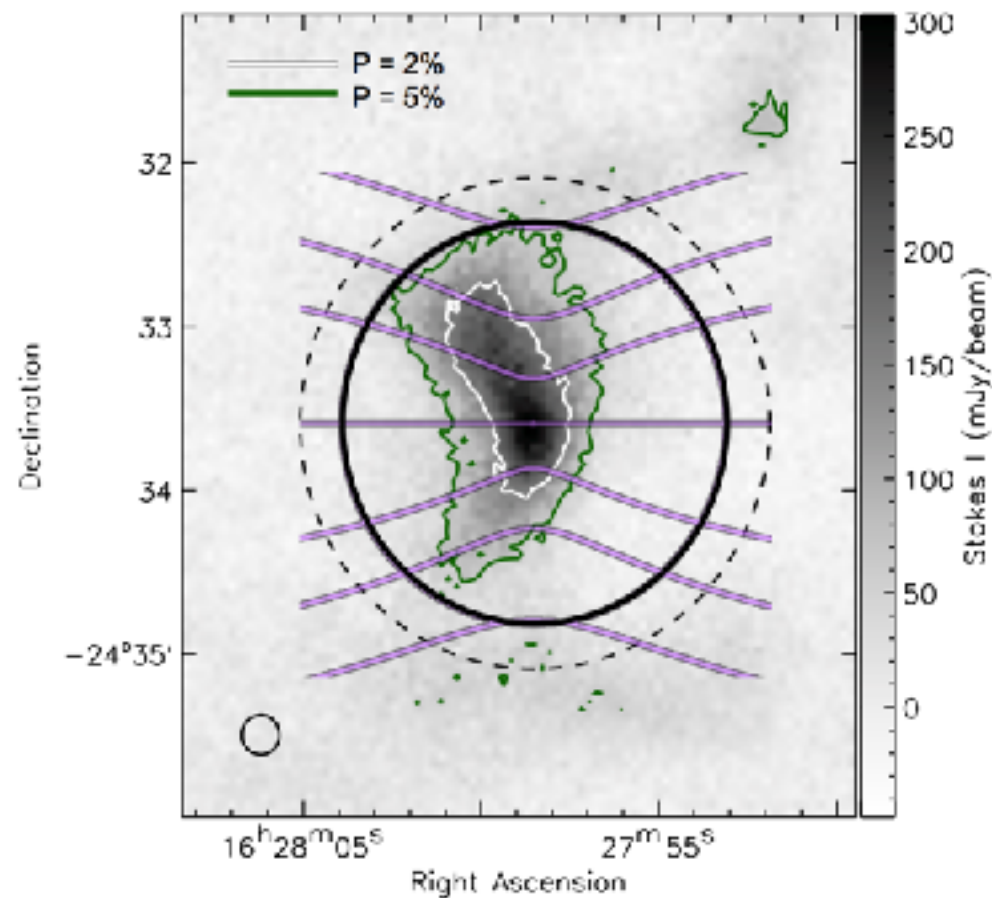
## Slide Summary for a New Polarimeter at the JCMT - Sarah Sadavoy

I'm especially interested in studying magnetic fields in starless cores and isolated clouds. These objects are often more extended and less dense, which makes them less efficient to observe in millimeter polarization detections (e.g., with ToITeC or NIKA-2) or with interferometers like ALMA. Moreover, they can lack contrast for FIR polarization with SOFIA, which means that submillimeter polarization is the best tool we can use to trace the large scale magnetic field morphology. These clouds are interesting targets because they have simpler density and temperature structures than protostellar cores, and that makes them easier to model as three-dimensional objects.

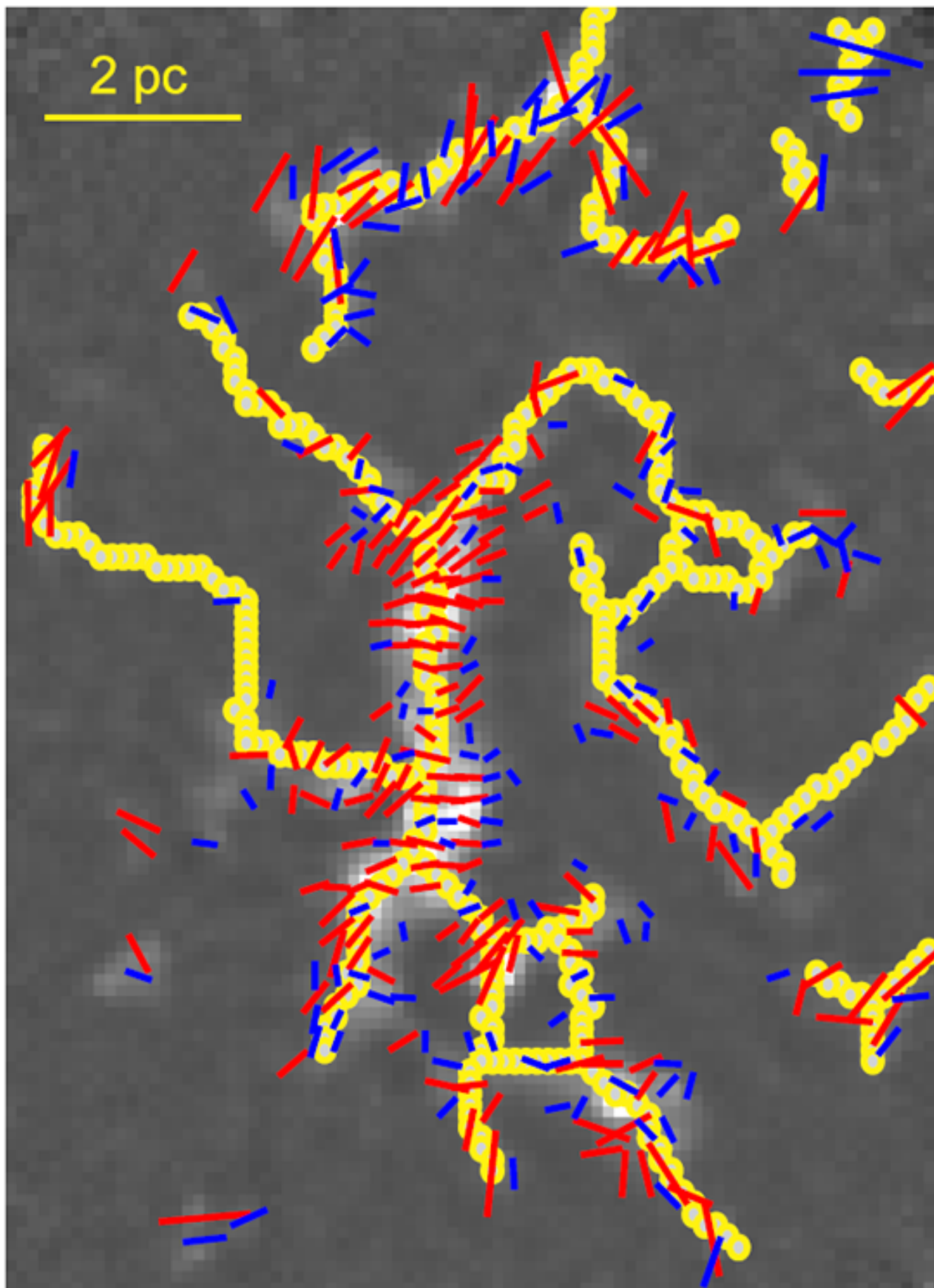
A faster, more sensitive POL2 camera would enable a larger sample of such objects in different environments to trace magnetic fields at the onset of star formation or under extreme conditions. Figure 1 shows POL-2 observations of Oph-C, a starless core in Ophiuchus, from Liu et al. (2019). These data show a relatively uniform polarization structure throughout the core, although many of the vectors have  $P/dP < 3$ . Deeper observations would more reliably capture the polarization toward the core center, where the field orientation is expected to change. Figure 2 shows an example of such a field morphology overlayed on the HMM1 starless core. We expect a flux-frozen magnetic field to be pinched toward a centrally concentrated core. The contours in Figure 2 show the areas where we expect to detect polarization at  $> 2\%$  and  $> 5\%$  with POL-2 in 28 hours. The proposed instrument will enable faster mapping of regions like HMM1 at higher sensitivities, and also the opportunity to conduct surveys.



**Figure 1:** POL-2 observations of the starless core Oph-C from Liu et al. (2019). Yellow line segments have  $P/dP > 2$ , cyan segments have  $P/dP > 3$  and are more reliable.



**Figure 2:** The HMM1 starless core in Ophiuchus. Background is 850  $\mu$ m data from Pattle et al. (2015). Purple lines show the expected magnetic field morphology for a centrally concentrated prolate spheroid (e.g., Myers et al. 2018) with a mass and size similar to HMM1. Contours show the areas where we expect to detect 2% and 5% polarization at  $> 3$ -sigma with POL-2 in 28 hours of Band 2 weather. The new instrument would be able to map this region to higher sensitivity in less than half the time with POL-2. Image from accepted POL-2 proposal (PI S. Auddy)

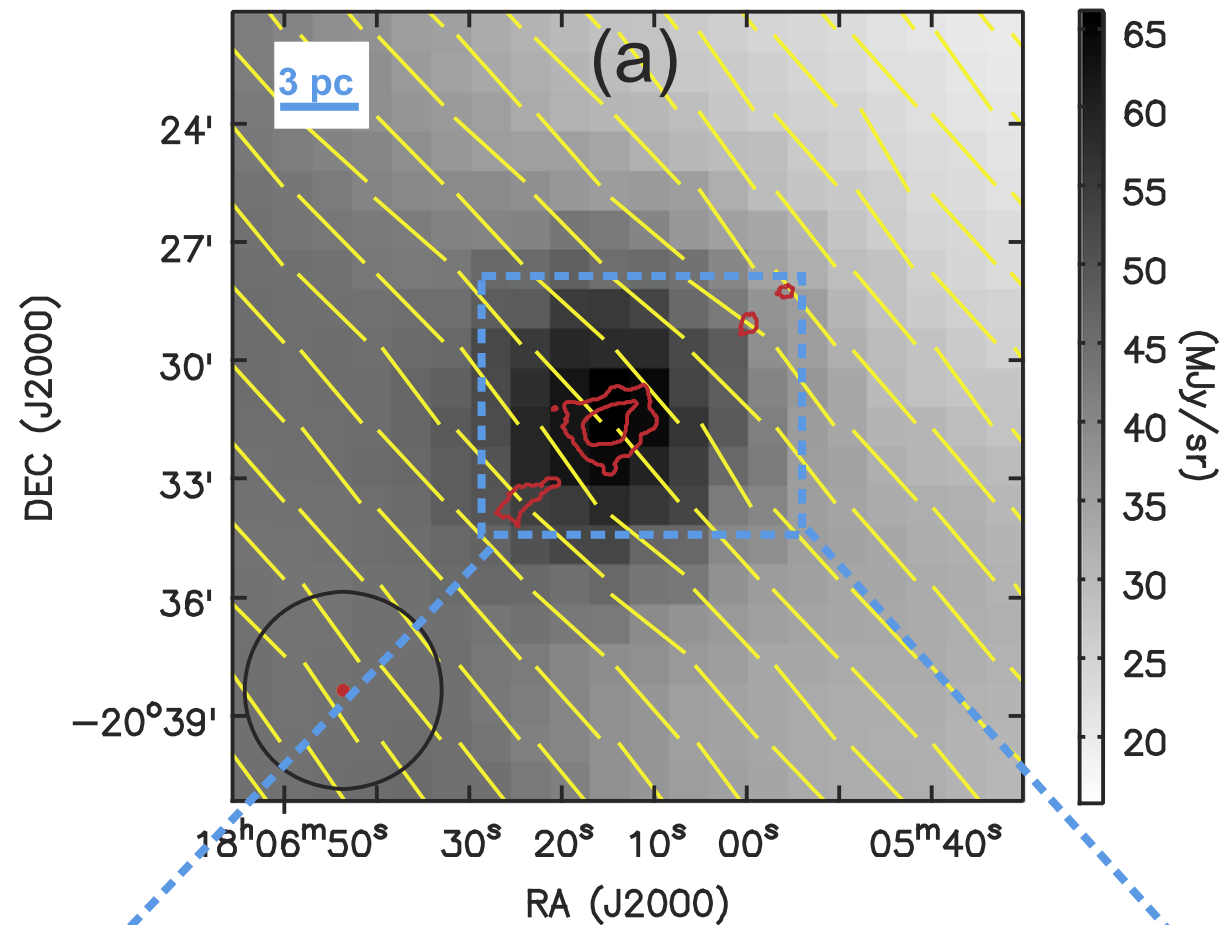


*First dust continuum polarization map of a distant massive infrared dark cloud with the JCMT/POL-2, showing a network of filaments and well ordered magnetic fields (Liu et al. 2018, ApJ, 859, 151).*

*WE used nearly 30 hrs to complete the observations  
Of this IRDC with two paintings.*

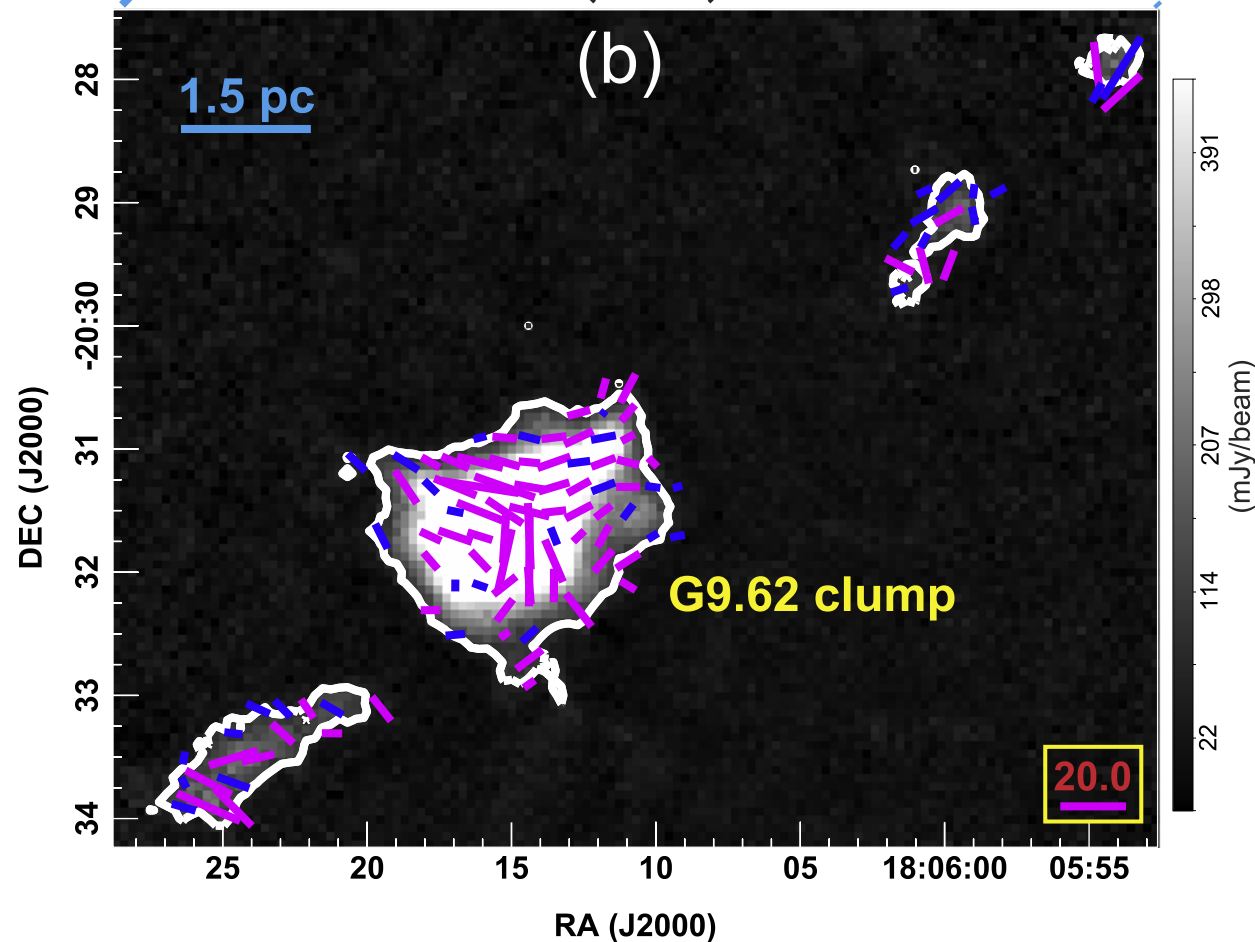
*With the new camera, we can reduce the on-source time  
by a factor of 20!!! It means that we can observe a large  
sample of distance IRDCs with reasonable survey time*





**We observed a bright ( $>1$  Jy/b) high-mass star forming region G9.62+0.19 with only two hours and achieved very high S/N (Liu et al. 2018, ApJL, 869, L5).**

**It is possible to observe hundreds of such high-mass star forming clumps (or filaments) with less than 100 hrs in total with the new camera**





Polarimetry is the an incredibly important field to understand the structure, strength, role of magnetic fields in the process of star-formation. The story starts with Hall and Hiltner's efforts in 1949 using polarimetry as a probe to visualise interstellar magnetic fields. The progress is made since then in all regimes of electromagnetic spectrum by improving the sensitivity and performances of the instruments. An upgrade in the JCMT SCUBA and POLarimeter is another such step contributing to the better understanding of capabilities of polarimetry in understanding interstellar B-fields. Following are some benefits which observers will have from this SCUBA-2 upgrade.

**Enhancement in pixel sensitivity:** This is majorly going to help in mapping fields in faint cloud cores. I recently ("first time") observed a core L1521F (Soam et al. submitted to ApJ) containing a Very Low Luminosity object (VeLLO) using POL-2. These are special class objects which give clues on formation of proto-brown dwarf candidates. I figured that if I keep the same rms required for mapping the B-fields in this core, and if sensitivity is increased by three times, I will just need 3 hours to obtain what I obtained in 10 hours. Thus, enhancement in sensitivity is important for going towards mapping field geometries in cores at lowest end of mass spectrum.

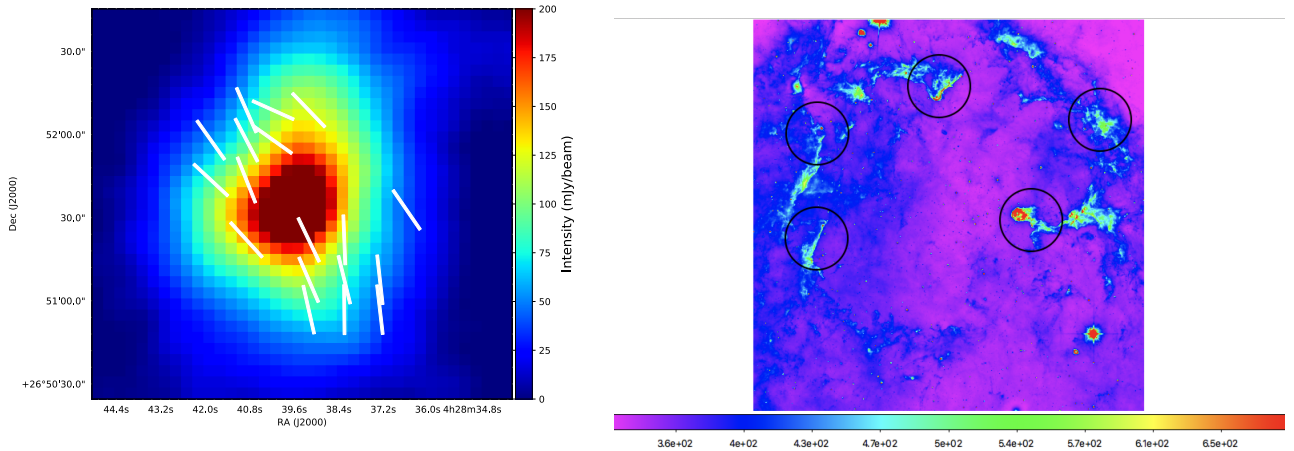


Figure 1: *Left: Observed B-fields in L1521F core. An enhanced sensitivity may increase the number of detections providing a better sample for B-fields estimation. Right: IC1396 HII region seen in WISE 12um image shown with JCMT FoVs. The bigger FoV can cover the interesting boundaries of the region within few attempts.*

#### **Benefit for investigating grain alignment:**

The enhanced sensitivity will aid in probing the polarization in highly evolved starless cores such as L1544 and L183 which play a very important role in understanding the grain alignment process. Recently, we proposed L183 at JCMT POL-2 to combine the submm pol data with optical and NIR pol data to investigate the "depolarization" in the core. There is no embedded source in starless cores so possibilities of enhanced RAT in denser regions are ruled out. Therefore, polarization observations in starless cores make a very good set of targets to understand the RAT due to ISRF. This will be only possible when JCMT will be able to attain signal in these very faint cores. The enhancement in sensitivity is a good hope in the direction of investigating "Polarization holes"

#### **Larger FOV and faster scanning speed:**

This aspect is important to map larger regions and avoid mosaicing of images. For instance, the extended sources such as IRDCs and brighter HII regions can be covered with better sensitivity and reduction in observation time. IC1396 is a very good example where we can map B-fields on the edges of expanding HII regions using bigger FOV of JCMT.

**Possibility of spectropolarimetry?** I am curious to know about any possible future spectropolarimetric observations with JCMT?

# Goal of the WP

- To show community demand for new instrumentation

**Community** = astronomers who are interested in the camera

+ astronomers who are potentially interested in the camera +  
astronomers who do not know the camera project + potential referees in other fields, i.e., non astronomers

## (Implicit) Mission of the WP

- To support funding in each partner

Get endorsement from astronomers who are potentially interested and who do not know for us to convince referees

# Goal of the WP

- To show community demand for new instrumentation

**Community** = astronomers who are interested in the camera  
+ astronomers who are potentially interested in the camera +  
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(Impl

We agreed that the below is crucial to the WP.

- To support funding in each partner

Get endorsement from astronomers who are potentially interested and who do not know for us to convince referees

# Guide-to-the-new-850um-MKID-camera-performance.pdf

<https://www.eao.hawaii.edu/EAO-Futures-Discussion-2019/Continuum%20Discussion?action=AttachFile&do=view&target=Guide-to-the-new-850um-MKID-camera-performance.pdf>

<b>Guaranteed mapping speed increase</b>	10x compact <sup>1</sup> , 10x large <sup>2</sup> maps	20x for polarimetry mapping
<b>Aspirational mapping speed increase</b>	20x large maps	40x for large polarimetry maps

<b>Target Date</b>	<b>Milestone</b>
October 2022	New 850 $\mu$ m instrument on-sky at JCMT
October 2024	New 450 $\mu$ m instrument providing 10x faster mapping than SCUBA-2 (20x POL-2) or an upgraded array to provide multi-chroic pixels
January 2026	New Large Format Heterodyne Array. 8x faster mapping than HARP. 2 sidebands and frequency range of 220 – 370GHz

# Boundary conditions to the WP

- Due: June 30th (may be extended up to the end of July)
- Nine page limit, including figures, reference
  - Focus on what can be achieved at 850 micron
  - Devote less than two pages to potential - future upgrades e.g., 450 micron demands

# Boundary conditions to the WP

- Due: June 30th (may be extended up to the end of July)
- Nine page limit, including figures, reference
  - Focus on what can be achieved at 850 micron

**We try to submit WP by the due, but, if it is difficult  
RSF will negotiate EAO**

**We confirmed that 850 camera is priority, other wish,  
e.g., 450, spectropolarimetry may be addressed w. lower  
priority.**

# Other WPs

- Cold cores and filaments
- Transient Events
- Evolved Stars
- Sub-mm Galaxies
- Nearby Galaxies
- East Asia VLBI

# Other WPs

- Cold cores and filaments
- Transient Events

Polarimetry is discussed only in our WP.

We should have good communication w. other WP team, especially Cold cores and filaments (led by Tie Liu in our team), Transient Events, and Nearby Galaxies.

At certain point, Keping will exchange ideas w. Nearby Gal. team because his interests have some overlap w. theirs, and key personals in nearby Gal. are working at Nanjing U.



# A proposal toward our WP

- Structure/format of each scientific subject
- Overall structure of the WP

# A proposal: format of each subject

For each subject, we argue,

1. Brief **summary** of the research subject

- includes state-of-art science with w. POL-2 and/or other instruments
- , if possible, ends with "*questions to be addressed*" (see the next slide for examples)

2. Describe **what** the new camera allows us to enhance the current cutting-edge science. Try to address as *quantitative* as possible.

✱ A figure may be included in each subject

# A proposal: format of each subject

For each subject, we argue,

## 1. Brief summary of the research subject

- includes state-of-art science with w. POL-2 and/or other instruments
- , if possible, ends with "*questions to be addressed*" (see the next slide for examples)

## 2. Describe **what** the new camera allows us to enhance the current cutt *quantitative as p*

**We agreed that this is reasonable.**

✱ A figure may be included in each subject

# EXAMPLE: Questions to be addressed in EACH FIELD

- What is the role of ***B*** field in regulating the formation and evolution of molecular clouds ( $\sim 10$  pc), clumps ( $\sim 1$  pc), and cores ( $\sim 0.1$  pc) ?
  - \* What is the dynamical role of *B* field in regulating the formation and evolution of striation, filament-and-hub structures?
  - \* Are ***B*** fields inside filament ordered or random?
  - \* Do ***B*** fields play a significant role in fragmentation of molecular **clumps** and formation of **dense massive cores**? .... *B* fields in high-mass SF
- Over what density ranges are *B* fields coupled w. matters? ... ionization degree
- ***B*** fields in low-density region appear to be **ordered**, whereas **complex or random** in high-density: if this is a picture, what is the density of transition between them?
- **|B|** strengths in high-mass SFRs are usually observed to be higher than low-mass ones; is there enhancement mechanism?
- What is the dominant **dissipation mechanism of *B* fields** in each density range?
- Down to what size scale ***B*** field regulate gas kinematics? ... minimum size scale

# A proposal: structure of the WP

To organize individual subjects, we may consider an overall structure of the WP with options of,

1. conventional object-type-oriented structure.
2. astrophysics-oriented structure.

# Op.#1 Object-type oriented

## 1. Background, aims and organization of the WP

### 1. Study of B-fields w. new camera: objects

- 1.1. Formation/evolution of turbulent magnetized molecular clouds (e.g.,  $>1\text{ pc}$ )
- 1.2. Formation/evolution of turbulent magnetized of dense cores (e.g.,  $\sim 1-0.01\text{ pc}$ )
- 1.3. Formation/evolution of disk-jet-star system ( $<0.01\text{ pc}$ )
- 1.4. Late type stars
- 1.5. Super nove and cosmic ray accelerations
- 1.6. The Galactic center, including molecular tori, AGN jets
- 1.7. Nearby disk galaxies, dwarf galaxies, LIRG/ULIRGs
- 1.8. High-z universe and CMB polarization

### 2. Study of B-fields w. new camera: methodology

- 2.1. Dust-grain physics
- 2.2. Synergy w. molecular line observations
- 2.3. Synergy w. time-domain science

## 2. Synergy w. existing and future instruments/telescopes

## 3. Executive summary

# Op.#2 astrophysics oriented

1. Background, *ultimate aims* and organization of the WP

1. Study of B-fields w. new camera: objects

1.1. Interstellar B-fields

1.2. Circumstellar B-fields

1.3. Circumnuclear B-fields

1.4. Intergalactic B-fields

2. Study of B-field w. new camera: methodology

2.1. Dust-grain physics

2.2. Synergy w. molecular line observations

2.3. Synergy w. time-domain science

3. Synergy w. existing and future instruments/telescopes

4. Executive summary

# Ultimate goals beyond the new camera

## What will be legacies promised by the new camera?

- 📌 What is the origin of  $B$  fields in the universe?
- 📌 What are their roles in cosmic history?

Are there *primordial*  $B$  fields or  
are they produced by *astrophysical* process?



# Ultimate goals beyond the new camera

*Center of gravity can be defined*

*Primordial*

Circumstellar ***B***

*Primordial*

Circumnuclear ***B***

Interstellar ***B***

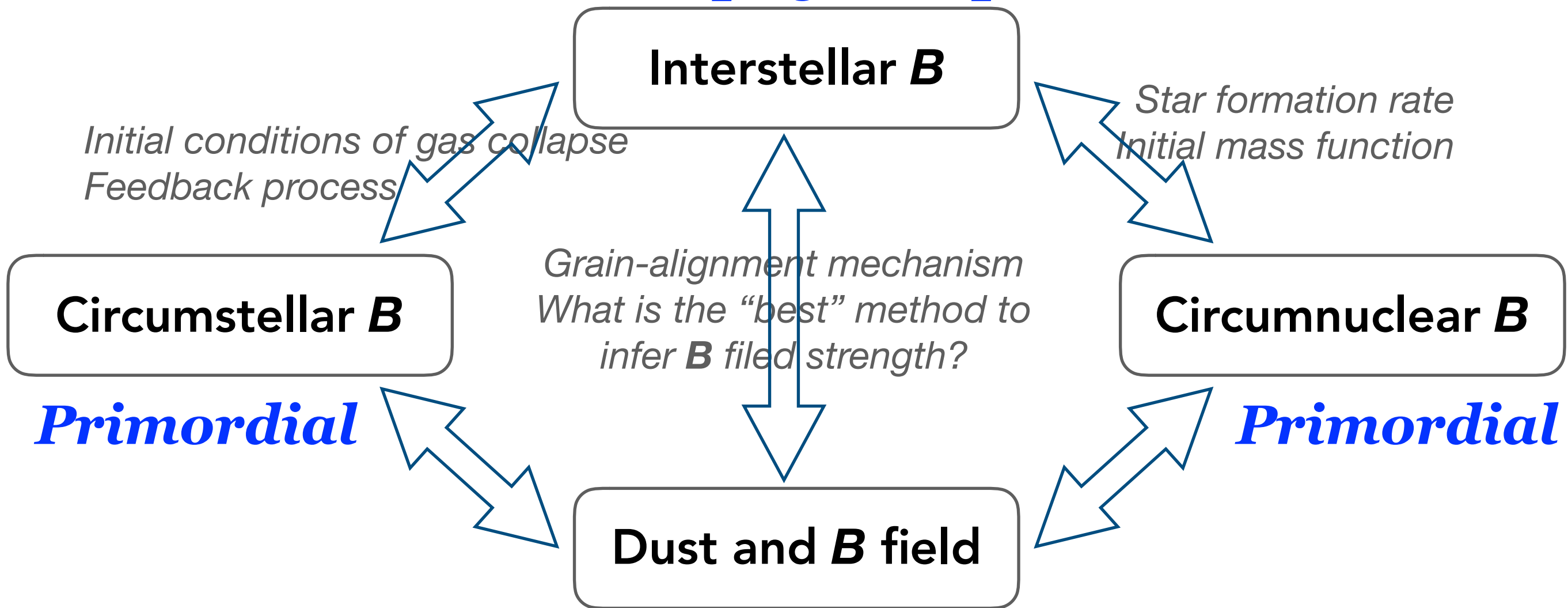
Intergalactic ***B*** field

*Primordial?, astrophysical process? or both?*

*Center of gravity cannot be defined*

# Ultimate goals beyond the new camera

*Primordial?, astrophysical process? or both?*



In most astrophysical process,  $B$  fields are passive in dynamics, however,  $B$  fields play significant roles in some stages.

**At what evolutionary stage, over what spatial scale, or/and over what density range do  $B$  field is playing key role**

# Structure of the WP: Op#1 vs. Op#2

## 1. Conventional object-type-oriented

**[Strong point]** Straightforward structure for *low-energy* astronomers

**[Weak point]** (i) Not so appealing to other fields, e.g., high-energy astronomers, planetary scientists, cosmologist etc, (ii) Not easy to cover (almost) all type of objects

## 2. Astrophysics-oriented structure

**[Strong point]** (i) Clear goals/structure for physicist, easy to appeal referees in other fundamental sciences, (ii) Clear goals in methodology — polarization imaging w. MKIDS

**[Weak point]** We need to *rescope* our object-oriented-studies to astrophysics-oriented one

# Structure of the WP:

## Op#1 or Op#2 ?

# Structure of the WP:

We discussed advantage and disadvantage of the dual options. Given the limited numbers of the pages (=9 pages) and the tight schedule (= due is end of this month), we decided to take Option #1.

There were a few opinions, including RSF, who favors Op#2. We therefore argued that the Executive Summary may be described w. the style of Option #2.

# Assignment of task: Op.#1

1. Background, aims and organization of the WP: **Furuya**

1. Study of B-fields w. new camera: objects

- 1.1. Formation/evolution of turbulent magnetized molecular clouds (e.g.,  $>1$  pc)
- 1.2. Formation/evolution of turbulent magnetized of dense cores (e.g.,  $\sim 1-0.01$  pc)
- 1.3. Formation/evolution of disk-jet-star system ( $<0.01$  pc)
- 1.4. Late type stars
- 1.5. Super nove and cosmic ray accelerations
- 1.6. The Galactic center, including molecular tori, AGN jets
- 1.7. Nearby disk galaxies, dwarf galaxies, LIRG/ULIRGs
- 1.8. High-z universe and CMB polarization

2. Study of B-fields w. new camera: methodology

- 2.1. Dust-grain physics
- 2.2. Synergy w. molecular line observations
- 2.3. Synergy w. time-domain science

2. Synergy w. existing and future instruments/telescopes

3. Executive summary: **Furuya**

# Additional task assignments

1. Check other WPs, try to cite other WPs: Furuya
2. Look for authors of subjects which cannot be covered by us: Furuya
3. Check the proposed capabilities, and convert them to physical ones (e.g., mJy/beam to  $\text{cm}^{-2}$  in column density) to support authors of each subject: ?????
4. Language corrections: Kate and/or Sarah
- 5.any others?

**RSF will report today's discussion to the people who could not join the telecom, and call for volunteer authors for each subsection of Op.#2.**

**We start writing the draft asap, the proposed format of Op.#2 will be used to start writing. Of course, we will be flexible to add, delete, and merge each (sub)sections accordingly.**