1. Science aim/goal (provide a high-level statement in 140 characters or less):
We aim to understand the role of magnetic fields and turbulence in star formation, connecting galactic-scale physics to protostellar cores.

(i) Scientific Importance:

Magnetic fields and turbulence are key regulators of the star-formation process at all spatial scales. Magnetic fields shape turbulence on the largest scales in the diffuse interstellar medium (ISM) and are responsible for the formation and evolution of protostellar cores, envelopes, disks, outflows, and jets. Turbulence itself carries a significant fraction of the energy in our galaxy, and represents the direct coupling of matter from galactic to the scales of protostellar envelopes. Over the last two decades a vast amount of work has gone into characterizing magnetic fields and turbulence in the ISM from galaxy → cloud → protostellar core scales, using interferometers plus ground-, balloon-, and space-based single-dish instruments. The *Planck* satellite has recently mapped dust polarization across the entire Milky Way, but the images lack the spatial resolution to study magnetic fields and turbulence at the 1″ resolution that the FIRS will be able to achieve. Many crucial questions still remain unanswered, in particular regarding understanding the structure of magnetic fields and the drivers and dissipation of magnetohydrodynamic (MHD) turbulence. The FIR Surveyor (FIRS) would dramatically advance the field by enabling observations of dust polarization and turbulent shock tracers such as high-*J* CO and [CII] transitions across many orders of magnitude in spatial scale in the ISM. A high-resolution, high-sensitivity, and very wide-field map of both gas tracers and magnetic field orientation has never been possible, and would reveal the role of magnetic fields in ISM shocks.

(ii) Measurements Required:

In order to make major breakthroughs in our understanding of the roles of magnetic fields and turbulence in star formation, we require high-resolution, high-sensitivity, multi-wavelength, wide-field observations of (1) dust polarization in the FIR (at the peak of the dust SED, where dust is generally optically thin), which, unlike background starlight polarization, allows access to all spatial scales of magnetized turbulent flows with uniform coverage; and (2) well-resolved maps of high-energy FIR spectral lines, in particular of [CII] and the CO Spectral Line Energy Distribution (CO SLED), to trace turbulent shocks and to directly measure both energy injection scales and energy losses in the neutral ISM. The combination of FIR resolved-spectral-line and thermal dust polarization data will allow us to probe material of different densities and temperatures, and will help to determine where in the medium the emission is originating, thus allowing us to effectively produce tomographic maps of the magnetic field in the turbulent ISM over entire molecular clouds. Furthermore, observations at multiple wavelengths in the FIR will enable continued testing of dust-grain alignment theories.

(iii) Uniqueness to 10 micron to few mm wavelength facility:

Interferometers like ALMA, while providing high spatial resolution, are inefficient at large-scale mapping and recovering large-scale structure; furthermore, sampling far from the SED peak, (sub)millimeter telescopes miss much of the flux from the dust. Wide-field mapping in the FIR will complement large-scale polarization mapping efforts by (sub)millimeter single-dish telescopes such as BLASTPol (see Figure 1), JCMT (BISTRO survey with POL-2), the IRAM 30m (NIKA-2), and the LMT (Toltec instrument, planned). The FIRS will have much better sensitivity than these instruments, allowing mapping of material at much lower column density ($N_H < 10^{22}$ cm^{-3}).

(iv) Longevity/Durability: (with respect to expected 2025-2030 facilities)

SOFIA will be a good pathfinder for the FIRS, but the FIRS sensitivity will be much better, allowing us to map dust polarization spectral-line emission in regions inaccessible to SOFIA. Furthermore, while a ground-based telescope would be able to map individual spectral lines over wide area, such an instrument could not cover the SLED uniformly, which would preclude measuring the energy losses.

3. Figure:

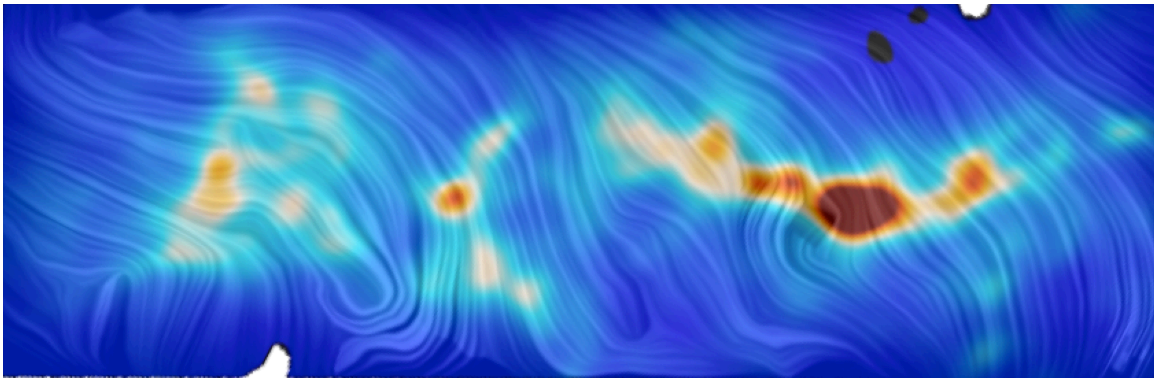

Figure 1. *A map of inferred magnetic field lines (texture) and total intensity dust emission (color scale) in the Vela C molecular cloud, from Fissel et al. 2016. This map, made with BLASTPol (the Balloon-borne Large Aperture Submillimeter Telescope for Polarimetry) is the most detailed magnetic field map ever made for a GMC forming high-mass stars.*

4. Table:

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	micron	200-500	100-600	CO(5-4) → CO(9-8), [CII], dust peak
Number of targets		3	30	Nearby molecular clouds
Survey area	deg.^{2}	10	1000	Covering |*b*|<5°: galactic plane and all nearby star-forming clouds
Angular resolution	arcsec	2″	1″	@ 100 microns
Spectral resolution	$\Delta\lambda/\lambda$		0.1 km/s	
Continuum sensitivity	µJy		<1 mJy	At 100 um. Exceeds SOFIA's HAWC+ by >2 OOM
Spectral line sensitivity	W m^{-2}	3×10^{-19}	1×10^{-19}	0.1 K in a 1 km/s channel
Dynamic range			1000	An high ALMA DR
Cadence				N/A
Any other requirement		0.5% ±5° angle	0.5% ±5° angle	**Polarization accuracy** for linear & circular. Best FIRS spec.

5. Key references: (Optional, at most three, reviews preferred)

- Andersson et al. 2015, ARA&A, 53, 501 [Interstellar dust grain alignment]
- Crutcher 2012, ARA&A, 50, 29 [Magnetic fields in molecular clouds]
- Elmegreen & Scalo, ARA&A, 2004, 42, 211 [Turbulence, including MHD]

6. Appendix

Polarization & magnetic fields

Here we justify the required parameters listed in the Table:

- Wavelength/band (100-600 microns)
  - This wavelength range covers the peak of the SED of the emission from star-forming clouds, and is not accessible from the ground. This also covers C^+ as well as several critical CO transitions.

- Number of targets (~30 molecular clouds) and survey area (1000 deg^2)
  - Ideally we would conduct a survey of all nearby molecular clouds for a statistical sample.

- Angular resolution (1″ at 100 microns)
  - Achieving 1″ at 100 microns (6″ at 600 microns) will allow us to probe the magnetic fields and turbulent structures down to the scales immediately surrounding forming protostars, thus allowing us to trace magnetic fields and characterize the turbulent cascade down to the angular scales where ground-based instruments like ALMA can take over. 1″ is unprecedented angular resolution for an instrument designed for large-area mapping.

- Spectral resolution (0.1 km/s)
  - Typical spectral resolution for studies of turbulence.

- Continuum Sensitivity (<1 mJy)
  - An order of magnitude better sensitivity than SOFIA, coming within an order of magnitude of the typical sensitivity of an ALMA observation at similar wavelengths.

- Spectral line sensitivity (1×10^{-19})
  - Achieving 0.1 K in a 1 km/s channel

- Dynamic range (1000)
  - A dynamic range of 1000 (which is an excellent dynamic range for a millimeter-wave ALMA image) allows robust characterization of both the faintest and brightest structures in the field of view, which is critical for mapping turbulence across many orders of magnitude in spatial scale.

- Polarization accuracy (0.5% in linear and circular polarization, ±5° in pol. angle)
    - This is the best achievable spec by the FIRS, and would allow detection of polarization at a very low level, which would allow for mapping of magnetic fields both in weakly polarized sources, as well as in very weak sources with a substantial polarization fraction.

Turbulence

A complementary approach for characterizing turbulence would be to add an absorption study of CH^+ and SH^+, two key species for constraining the turbulence parameters. With a 10-m class telescope, a large number of sources will be available including nearby galaxies.

References (turbulence)

- Mac Low & Klessen 2004, RvMP, 76, 125
- Godard et al. 2014, A&A, 570, 27
- Pon et al. 2014, MNRAS, 445, 1508