Magnetic fields in forming stars with the ngVLA

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1. Introduction

The magnetic field plays an important role in every stage of the star-formation process from the collapse of the initial protostellar core to the star’s arrival on the main sequence. Consequently, the goal of this science case is to explore a wide range of magnetic phenomena that can be investigated using the polarization capabilities of the Next Generation Very Large Array (ngVLA). These include (1) magnetic fields in protostellar cores via polarized emission from aligned dust grains, including in regions optically thick at wavelengths observable by the Atacama Large Millimeter/submillimeter Array (ALMA); (2) magnetic fields in both protostellar cores and molecular outflows via spectral-line polarization from the Zeeman and Goldreich-Kylafis effects; (3) magnetic fields in protostellar jets via polarized synchrotron emission; and (4) gyrosynchrotron emission from magnetospheres around low-mass stars.
2. Scientific Importance & Anticipated Results

2.1. Dust polarization in low-mass protostellar objects

Mapping the morphology of magnetic fields in the cores and envelopes surrounding young, low-mass protostars is critical to further our understanding of how magnetic fields affect the star-formation process at early times. Under most circumstances, and for the typical grain sizes found in the ISM (≪100 µm), elongated dust grains are thought to align themselves with their long axes perpendicular to magnetic field lines (e.g., Hildebrand 1988; Lazarian 2007; Hoang & Lazarian 2009; Andersson et al. 2015), resulting in thermal radiation from the grains that is polarized perpendicular to the magnetic field (see Heiles et al. 1993 for a description of not only linear dust polarization, but also the other polarization mechanisms that are mentioned in the following sections). Thus, this type of observation can be used to infer the magnetic field morphology in the plane of the sky.

Polarized thermal dust emission from both low- and high-mass protostellar objects has been studied extensively at millimeter wavelengths at 1–2″ resolution by the Berkeley Illinois Maryland Association millimeter array (BIMA; e.g., Rao et al. 1998; Girart et al. 1999; Lai et al. 2001; Matthews et al. 2005; Cortes & Crutcher 2006; Kwon et al. 2006), the Submillimeter Array (SMA; e.g., Girart et al. 2006, 2009; Tang et al. 2009; Alves et al. 2011; Zhang et al. 2014), the Combined Array for Research in Millimeter-wave Astronomy (CARMA; e.g., Hull et al. 2013; Hughes et al. 2013; Hull et al. 2014; Stephens et al. 2014; Segura-Cox et al. 2015), and ALMA (e.g., Cortes et al. 2016; Hull et al. 2017b,a; Cox et al. 2018; Maury et al. 2018). With the upgraded Karl G. Jansky Very Large Array (JVLA), it has recently become possible to begin performing dust polarization studies at centimeter wavelengths, using the highest-frequency bands available: K, Ka, and Q bands (18–50 GHz). Both Cox et al. (2015, see Figure 1) and Liu et al. (2016) studied the polarized dust emission at 37 and 43 GHz from NGC 1333-IRAS 4A, one of the first sources to be imaged in full polarization and high resolution at submillimeter wavelengths using the SMA (Girart et al. 2006). More recently, Liu et al. (2018) have studied the 40–48 GHz polarization toward the Class 0 protostar IRAS 16293, another bright source that was an early target for millimeter-wave polarization observations (Rao et al. 2009, 2014).

For the JVLA, NGC 1333-IRAS 4A and IRAS 16293 are two of the very few sources with polarized dust emission bright enough that they can be imaged within a few hours. A typical protostellar core may be ∼10× fainter than IRAS 4A or IRAS 16293. In order to probe the magnetic field in the innermost ∼1000–100 au regions (which can be resolved with the 1000–10 mas scales recoverable with the ngVLA) of these more “normal” objects, we need the sensitivity and the resolution of the ngVLA at the ∼30–90 GHz wavelengths where there is still appreciable dust emission, but where material is still optically thin even in the densest inner regions. For example, the peak flux of IRAS 4A at 30 GHz as detected by Cox et al. (2015) is ∼3000 µJy in an 0.25″ synthesized beam. In <1 hr of integration time, the ngVLA will be able to detect 1% polarized dust emission at a frequency of 30 GHz at a level >3σ in objects 10× fainter than IRAS 4A.

2.1.1. Polarization in protoplanetary disks

Regarding protoplanetary disk polarization at long wavelengths: a notable non-detection is HL Tau—one of the brightest known protoplanetary disks—where exceptionally
deep 7 mm VLA observations by Carrasco-González et al. (2016) were unable to detect dust polarization, despite having an rms noise of ∼3 μJy beam⁻¹ (after integrating for nearly 15 hrs on source), simply because the dust emission is too faint at those long wavelengths. Polarization fractions of ∼1% are expected in protostellar disks; thus, an order-of-magnitude improvement in sensitivity is needed in order to detect polarization in these sources.

HL Tau is ∼10× brighter than a “typical” extended protoplanetary disk: for example, the subsample of transition disks in the ALMA survey of ρ Oph by Cox et al. (2017) has a median integrated flux of ∼260 mJy at 850 μm, whereas HL Tau has an integrated flux of brightness of ∼2.4 Jy at the same wavelength (Stephens et al. 2017). Assuming this approximate factor of 10 ratio holds at longer wavelengths, a typical large disk would have a peak 3 mm flux of ∼3 mJy in a ∼0.5″ beam, 10× lower than the value reported in Stephens et al. (2017). In < 1 hr of integration time, the ngVLA will be able to detect 1% polarized dust emission at a wavelength of 3 mm at a level >3σ in such an object, enabling studies of long-wavelength polarization in a statistically significant sample of many of the famous, extended disks present in a wide range of star-forming regions. These studies will also allow us to characterize the polarization in regions optically thick at ALMA wavelengths (e.g., in HL Tau; ALMA Partnership et al. 2015; Carrasco-González et al. 2016; Jin et al. 2016); will enable us to characterize the polarization properties of grains by observing the polarization spectrum—i.e., the source polarization as a function of wavelength—from infrared to (sub)millimeter to centimeter wavelengths; and will allow us to better understand the physics behind the transition from magnetic alignment of dust grains to other polarization mechanisms (see below), which are thought to be dependent on dust-grain growth.

Figure 1. VLA 8 mm polarization observations of the embedded Class 0 protostellar source NGC 1333-IRAS 4A (Cox et al. 2018). Contours show total intensity (Stokes I) emission; red line segments show the inferred magnetic field, rotated by 90° relative to the dust polarization. IRAS 4A is one of the brightest low-mass protostellar sources known; typical sources are not bright or polarized enough for dust polarization to be detected toward them with the JVLA.
Recent ALMA polarization observations toward several protoplanetary disks have revealed different mechanisms causing the polarization: self-scattering at 870 μm (observational: Kataoka et al. 2016; Stephens et al. 2017; Lee et al. 2018; Girart et al. 2018; Hull et al. 2018; theoretical: Kataoka et al. 2015; Yang et al. 2017), alignment with the dust-emission gradient at 3 mm (observational: Kataoka et al. 2017; theoretical: Tazaki et al. 2017), and a seemingly linear combination of the two at 1.3 mm (Stephens et al. 2017). Recent (sub)millimeter ALMA polarization observations of younger, more embedded Class 0/I protostars have even shown hints of scattering in the innermost, ~100 au regions of a few sources (Cox et al. 2018; Harris et al. 2018; Sadavoy et al. 2018). However, self-scattering is a highly wavelength-dependent phenomenon, and it is maximum around a wavelength of $2\pi a_{\text{max}}$, where $a_{\text{max}}$ is the maximum grain size. Thus, at long wavelengths far from this value (i.e., those accessible to the ngVLA), it may be possible that grains aligned with the magnetic field dominate the dust polarization.

Considering that ALMA will eventually have Band 1 (~40 GHz), and that it already has a functioning polarization system at Band 3 (~100 GHz), lower-frequency K and Ka band observations with the ngVLA would be complementary, and possibly unique to the instrument. Also, without considering the unknown polarization efficiency as a function of wavelength, 18–40 GHz observations are easier than higher Q band observations at the JVLA site due to the weather constraints.

### 2.2. Spectral-line polarization: Zeeman and Goldreich-Kylafis effects

Molecular and atomic lines are sensitive to magnetic fields, which cause their spectral levels to split into magnetic sub-levels. When threaded by a magnetic field, atomic hydrogen and molecules with a strong magnetic dipole moment will have the degeneracy in magnetic sub-levels lifted for states with non-zero angular momentum. Examples lying within the nominal 1.2–116 GHz frequency range of the ngVLA include lines from H at 1.42 GHz; OH at 1.61–1.72 GHz & 6.01–6.05 GHz; CH$_3$OH at 6.7, 36, & 44 GHz; C$_4$H at 9.5 & 19.0 GHz; CCS at 11, 22, 33, & 45 GHz; C$_2$H at 87 GHz; SO at 13, 30, 63, 86, & 99 GHz; and CN at 113.1–113.6 GHz. This lifting of the degeneracy will split the radio frequency transitions into a number of linearly and elliptically polarized components slightly separated in frequency. This is known as the Zeeman effect (Troland & Heiles 1986; Heiles et al. 1993; Crutcher 1999). Measuring this effect is the only way to directly measure the magnetic field strength (yielding either the line-of-sight field strength for Zeeman-broadened transitions, or the entire field strength for transitions that are completely split, e.g., Galactic OH masers$^1$). Directly measuring the magnetic field strength is essential to achieve a more robust understanding of the dynamical relevance of the magnetic fields before and during the collapse of the star-forming core. Galactic OH masers can also be used to map out the large-scale magnetic field in the Milky Way since the star-forming regions in which they’re found seem to retain information about the large-scale field in their vicinity (Davies 1974; Reid & Silverstein 1990). The ngVLA will play a critical role in extending Zeeman measurements beyond our Galaxy by detecting magnetic fields from extragalactic OH masers in nearby

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$^1$ Linear and circular polarization from maser emission of centimeter and millimeter lines of SiO, CH$_3$OH, H$_2$O, and OH would allow us to probe the dense environment around young stellar objects and the circumstellar material around evolved stars.
galaxies like M33 and M31 and from OH megamasers in distant starbursting galaxies (Robishaw et al. 2008).

For other types of molecules, linear polarization can arise whenever an anisotropy in the radiation field yields a non-LTE population of magnetic sub-levels. This is the so-called Goldreich-Kylafis (G-K) effect, which traces the plane-of-sky magnetic field orientation (Goldreich & Kylafis 1981, 1982; Kylafis 1983; Deguchi & Watson 1984). This effect is expected to be easiest to observe where the lines have an optical depth of $\sim 1$; when the ratio of the collision rate to the radiative transition rate (i.e., the spontaneous emission rate) is also $\sim 1$; and for the lowest rotational transitions of simple molecules such as CO, CS, HCN, SiO, or HCO$^+$. So far, the G-K effect has been measured mostly around molecular outflows (e.g., Girart et al. 1999; Lai et al. 2003; Cortes et al. 2005; Vlemmings et al. 2012; Girart et al. 2012; Ching et al. 2016). This suggests that G-K observations with the ngVLA at 7 mm (SiO, CS) or 3 mm (CO, SiO, HCO$^+$) will provide new insight into the properties of the putative helical magnetic field near the launching point of bipolar outflows around young stellar objects, where a significant fraction of the outflow appears to be molecular. Molecular outflows from protostellar objects tend to have a parabolic, multi-layered, “onion-skin” type structure, with the lowest/highest-velocity material located in the outermost/innermost shells. Therefore, measuring the polarization at different velocities enables us to reconstruct the 3-dimensional magnetic field morphology in the source.

Polarization from thermal lines requires detection of emission with a high signal-to-noise ratio at high spectral resolution. The layout of the ngVLA (including the high-density central core of antennas) will yield excellent brightness sensitivity over a range of spatial scales relevant to star formation (approximately 10–1000 mas). The types of sources where the ngVLA would have a clear science impact detecting the Zeeman splitting and the G-K effect include the inner regions of various types of star-forming cores (e.g., warm cores, hot corinos, hot cores), proto/circumstellar envelopes, the launching regions of molecular outflows and jets, and disks.

2.3. Synchrotron emission from protostellar jets

Jets play an important role in the star-formation process. They are believed to regulate accretion from the disk onto the protostar at the earliest (Class 0/I) stages of star formation. However, jets are not only important in the field of star formation—protostellar jets are usually considered a less energetic manifestation of the powerful relativistic jets driven by supermassive black holes at the center of active galaxies or stellar-mass black holes in our own Galaxy (e.g., de Gouveia Dal Pino 2005). Despite their importance, we still do not know how protostellar jets are launched and collimated. In the case of relativistic jets, observations of polarized synchrotron emission suggest that a helical configuration of the magnetic field is responsible for the collimation of the jet (e.g., Lyutikov et al. 2005; Gómez et al. 2008). In the case of protostellar jets, theoretical models also point to a fundamental role of the magnetic field, which is thought to have a helical configuration (e.g., Shu et al. 1994); helical magnetic fields are a consequence of the rotation of the protostar-disk system. As for the collimation of jets, they may be collimated internally. However, other collimation mechanisms by external agents, such as ordered magnetic fields present in the protostar’s neighborhood, have also been proposed (e.g., Albertazzi et al. 2014); some observations are consistent with external collimation mechanisms (e.g., Carrasco-González et al. 2015).
The magnetic field is extremely difficult to study in the case of protostellar jets. Jets have been observed in great detail at radio wavelengths, although they emit mainly continuum thermal radiation (e.g., Anglada 1996), which contains no information about the magnetic field. However, in the last decades, very sensitive observations have shown that synchrotron emission can also be present in some protostellar jets (see Carrasco-González et al. 2010 and references therein). While the material in the jet moves at velocities of a few \( \times 100 \) km s\(^{-1}\), it has been shown that under some conditions, a population of particles can be accelerated up to relativistic velocities in strong shocks against the ambient medium (e.g., Rodríguez-Kamenetzky et al. 2016). Under these conditions, these accelerated particles can emit synchrotron emission, thus allowing the study of the magnetic field in the jet via synchrotron polarization. However, synchrotron emission in these objects is extremely weak, with intensities on the order of only a few \( \times 10 \) Jy in Stokes \( I \). At the beginning of the 2000s, we only knew of a handful of bright objects that show hints of synchrotron emission (i.e., negative spectral indices at centimeter wavelengths). In the last few years, more candidates have been detected as a result of the recently improved sensitivity in the ATCA and JVLA (e.g., Purser et al. 2016; Osorio et al. 2017). Yet, it has only been possible to detect linearly polarized emission in a single object, HH 80-81 (Carrasco-González et al. 2010, see Figure 2). Even though HH 80-81 is the brightest known protostellar jet, this unique detection at a single wavelength (6 cm) was only possible with significant observational effort (15 hrs of observations with the pre-upgrade VLA). Therefore, given the sensitivity of current instruments, it is still prohibitive to extend this study to multiple wavelengths in a sample of several protostellar jets.

In order to infer the 3-dimensional configuration of the magnetic field in the jet it is necessary to study the properties of the polarization of the synchrotron emission at several wavelengths. For example, for a helical magnetic field, we expect to observe gradients of the polarization fraction and the rotation measure (RM) across the jet width (Lyutikov et al. 2005). This implies the necessity to observe with high sensitivity to detect very low polarization fractions in intrinsically weak emission, and with high angular resolution to resolve the jet width (a few \( \times 10 \) milliarcseconds). In principle, these requirements could be reached by the JVLA. However, protostellar jets are very dense (electron densities of the order of a few \( \times 1000 \) cm\(^{-3}\)), and thus large RMs are expected. High sensitivity is currently achieved by averaging large frequency ranges. However, this introduces depolarization across the bandwidth when large RMs are present, rendering the polarized signal impossible to detect. It is therefore necessary to obtain high sensitivities even in narrow frequency ranges, which can only be achieved by increasing the observation time and/or the number of antennas in the interferometer.

Finally, it is not only desirable to detect polarization at several frequencies, but also at very different physical scales. The jet is expected to show complex morphology: extended diffuse emission, bow shocks, extended lobes, highly collimated parts, and compact internal shocks (e.g., Rodríguez-Kamenetzky et al. 2017). We also expect to see changes in the density across and along the jet. All of these characteristics imply dramatic changes of the properties of the emission (e.g., RM, brightness, and polarization fraction) at different scales. These changes can actually be used to obtain information about the jet’s physical structure by, for example, using new wide-band spectropolarimetry modeling techniques that have been successfully applied to very bright, but unresolved, radio galaxies (e.g., O’Sullivan et al. 2017; Pasetto et al. 2018). While this type of study would be very difficult to perform in distant extragalactic jets, in nearby protostellar jets it could be performed simply by being sensitive simultane-
Figure 2. Observations of linearly polarized emission at 6 cm in the protostellar jet HH 80-81 (Carrasco-González et al. 2010). This is the first and only time that polarized emission has been detected in a protostellar jet. This result demonstrated that detecting polarized synchrotron emission is possible in protostellar jets, and allowed the study of the magnetic field in this object using techniques similar to those used in relativistic jets. However, the weakness of the emission and the likelihood of large rotation measures make it extremely difficult to extend this kind of study to other wavelengths and/or protostellar jets using current instruments. Left: Color scale is the linearly polarized emission at 6 cm. Line segments indicate the polarization orientation of the electric field. Contours are the total 6 cm emission from the protostellar jet. Right: White line segments indicate the orientation of the inferred (projected on the plane of the sky) magnetic field obtained from the polarization measurements. Color scale is the total 6 cm emission of the jet. The apparent magnetic field is parallel to the direction of the jet. This is consistent with a helical magnetic field configuration. However, in order to infer the 3-dimensional configuration of the magnetic field it is necessary to study the polarization properties at several wavelengths.
ously to scales from a few milliarcseconds to several arcseconds. This will be easily achieved by an interferometer such as the ngVLA, with a large number of antennas spread over a few thousand kilometers.

2.4. Gyrosynchrotron from active magnetospheres around young stellar objects

Gyrosynchrotron radio emission from active magnetospheres is present in low-mass young stellar objects (YSOs) (e.g., Andre 1996) as well as their more evolved counterparts (Güdel & Benz 1993), including our Sun (Nita et al. 2004). Studying this emission in pre-main-sequence stars sheds light on their magnetic activity and the overall “space weather” that they drive, which has important effects on the chemistry and evolution of the surrounding protoplanetary and debris disks (e.g., Wilner et al. 2000).

The characterization of magnetospheric radio emission is also necessary for the proper analysis of YSO dust emission, because the two processes lead to emission at overlapping radio frequencies—in particular, the range of frequencies where the ngVLA will be most powerful. Non-thermal gyrosynchrotron emission can be distinguished from thermal emission mainly through its variability on timescales from minutes to months (Forbrich et al. 2015), its generally (but not always) negative spectral index (Garay et al. 1996), circular polarization fraction of a few to ∼20% (Andre 1996), and its brightness temperatures ≫10^4 K (Ortiz-León et al. 2017). Even the upgraded JVLA, however, has difficulty achieving the performance needed to fully understand YSO radio emission at centimeter wavelengths. In a study using the JVLA, Liu et al. (2014) characterized the radio flux, variability, and circular polarization of YSOs from Class 0 to Class III, achieving a noise of ∼20 μJy using observing blocks of a few hours and averaging over a few GHz of bandwidth. The results were consistent with earlier findings (e.g., Gibb 1999) showing that centimeter radio emission from YSOs (1) is dominated by free-free emission from collimated winds or radio jets in the early Class 0 and I stages (Anglada et al. 2015); (2) is difficult to detect in Class IIs (Galván-Madrid et al. 2014); and (3) is detectable in some but not all Class III YSOs (Forbrich et al. 2007; Dzib et al. 2013). The emission from Class IIIIs appears to be dominated by gyrosynchrotron radiation, but in Class IIs there are individual case studies pointing toward either free-free or gyrosynchrotron (Macías et al. 2016; Galván-Madrid et al. 2014).

The high sensitivity, wide frequency coverage, and angular resolution of the ngVLA would transform studies of both thermal and non-thermal YSO radio emission, allowing robust disentanglement of the two processes in snapshot observations as short as a few seconds. Scaling the nominal sensitivities reported by Carilli et al. (2015), the ngVLA could obtain full-polarization measurements with noise levels of ∼10 μJy in 5-second integrations. Moreover, the large simultaneous bandwidth would allow full characterization of the non-thermal radio SEDs and their overlap with free-free or dust thermal emission truly simultaneously, something that has not been possible with the VLA. It is quite likely that the non-thermal SEDs of YSOs have complexities due to multiple magnetospheric components, binary interactions (Salter et al. 2010), and other phenomena yet to be discovered.

The same attributes of the ngVLA that will make it a transformative tool for studies of YSO magnetospheres will produce similar gains in studies focusing on other objects with comparable magnetic properties. In particular, the magnetospheres of fully-convective YSOs can be dipolar and rotation-dominated, with strong commonalities to those found in very-low-mass stars and brown dwarfs, magnetic chemically pecu-
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liar (MCP) stars, and even the Solar System giant planets (Donati & Landstreet 2009; Schrijver 2009). The magnetism of these objects is quite different from that of the Sun, being driven by a fully-convective dynamo and resulting in large-scale current systems, coherent maser emission, and potentially trapped particle radiation belts (Hallinan et al. 2006; Williams 2017). The resulting radio emission is generally quite broadband and highly polarized (e.g., Williams et al. 2015), and current studies are often sensitivity-limited; for example, the JVLA is unable to detect even the 2 pc-distant ultracool dwarf binary Luhman 16AB (Osten et al. 2015). The ngVLA will therefore enable an entirely new class of time-resolved, full-polarization studies of magnetospheric activity in YSOs and beyond.

3. Measurements Required

Continuum polarization observations are relatively straightforward, generally requiring a single-pointing per source, integrating down to the point where a ∼1–3% polarization signal can be detected at the 3+ sigma confidence level across the desired region of the source. Spectral line polarization requires high spectral resolution, where the rule of thumb is ∼6 channels across the full-width-at-half-max (FWHM) of the line. This is especially important for Zeeman observations of masers, where a velocity resolution of <0.1 km/s is required. Polarization levels can be low, on the order of a few × 0.1%, so an accurate characterization of the instrumental polarization is required, down to a level of ∼0.1%, similar to what is achievable with the ALMA polarization system. The more compact sources (disks, protostellar envelopes, etc.) will generally fill only a fraction of the primary beam; however, for more extended sources, and in the event that there is more than one source (e.g., a few disks or protostars) in one field of view, either separate pointings and/or mosaics will have to be performed, or the wide-field polarization characteristics will have to be well characterized in order to correct for off-axis effects (see, e.g., work done by Jagannathan et al. 2017, 2018). Other standard polarization-specific calibration requirements involve solving for leakages (D-terms) and the XY (or RL) phase of the reference antenna.

The design of the ngVLA antennas and feeds should be informed by careful consideration of polarimetric goals—unfortunately, there is always a polarimetric sacrifice to be made for any given design. Linearly polarized radiation (Stokes Q and U)—especially weak polarization—is best measured via the cross-correlation of the orthogonal outputs from native circular feeds (with a penalty in measuring Stokes V); likewise, circularly polarized radiation is best measured by cross-correlating the outputs from orthogonal native linear feeds (with a penalty in measuring Stokes Q). New interferometers, except for the JVLA, are employing native dual-linear feeds. While these feeds can be converted to dual-circular by means of hybrids or dielectric quarter-wave phase shifters, such devices provide frequency-dependent polarization, operate over narrow bandwidths, and can increase not only the system temperature, but also the complexity and the cost of the receiver design.

An altitude-azimuth (alt-az) mount is ideal for polarization measurements because it causes a linearly polarized astronomical source to rotate relative to the feed as a source is tracked. This rotation greatly reduces systematic effects and makes calibration much easier. The Australian Square Kilometre Array Pathfinder (ASKAP) interferometer has been designed with dishes on alt-az mounts, but the designers have opted to rotate their entire dish structure with the sky—mimicking the behavior of an equatorial mount—in order to simplify wide-field polarimetric imaging. This is even better than a standard
alt-az mount because the polarization rotation can be done instantaneously, without having to wait for the angle to change while tracking.

A final polarization consideration involves the choice to use an off-axis Gregorian secondary-focus design for the dishes. When it comes to measuring polarization, symmetry is better: sidelobes and spillover radiation tend to be polarized by an amount that increases with asymmetry. Moreover, ground radiation is highly polarized.

4. Uniqueness to ngVLA Capabilities

The centimeter-wave/∼30 GHz capabilities of the ngVLA are unique in that the other extant telescope that can currently perform such observations—namely, the JVLA—doesn’t have the sensitivity to perform the type of observations we require. In the case of future ALMA Band 1 observations at ∼1 cm wavelengths, the ngVLA’s resolution and sensitivity will be much higher, enabling the studies we discuss above. Lower frequency telescopes probe physical phenomena that are completely different from the various polarization mechanisms we discuss above.

5. Synergies at Other Wavelengths

For continuum science, as an interferometer the ngVLA will fill a gap between the Square Kilometre Array (SKA)—which will address many different topics related to magnetic fields and polarization—and ALMA, which will look at many of the same objects, but at high frequencies where the material in the regions of interest (i.e., the inner parts of protoplanetary disks) is sometimes optically thick. The ngVLA will perform extremely high-resolution, high-sensitivity, targeted polarization science at the same time that the Origins Space Telescope (OST), if funded and constructed, is performing surveys of continuum and spectral-line polarization toward entire star-forming clouds across the Galaxy. The ngVLA will perform long-wavelength follow-up of observations from the myriad telescopes that are currently available (or are soon coming online) and have polarization capabilities at far-infrared and (sub)millimeter wavelengths, including ALMA, SOFIA (HAWC+ polarimeter), the James Clark Maxwell Telescope (JCMT; POL2 polarimeter), the Large Millimeter Telescope (LMT; TolTEC polarimeter), and the BLAST-TNG balloon-borne experiment.

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