I think it would be good if you mathematically defined visibilities somewhere.

define "Im{ }"

tion was reported by Houde et al. (2013) in a rotational transition of CO using the Caltech Submillimeter Observatory (CSO), a common tracer of ~~the~~ magnetic fields through LP (Crutcher 2012). The presence of circular polarization in a molecular transition can be explained with Zeeman splitting for some molecules/transitions possessing a significant magnetic momeny (e.g., CN), but CO is highly insensitive to the Zeeman effect. In addition, the observed Stokes V profile in Orion KL was positive and symmetric, which is also unexpected since Zeeman splitting usually gives rise to an approximately antisymmetric Stokes V profile. To explain this detection a model was proposed whereby linearly polarized light is converted to circularly polarized light through anisotropic resonant scattering (ARS) (Houde et al. 2013; Houde 2014). This was further tested in the supernova remnant IC443 by Hezareh et al. (2013), where the measured ~~circularly polarized~~ CP flux of CO lines ($J = 2 \rightarrow 1$) and ($J = 1 \rightarrow 0$) were '~~re-added~~ reinserted' into the measured ~~linearly polarized~~ LP flux to account for the LP-to-CP conversion & its effect on the PA. ~~correct the polarization angles~~. They found that the ~~polarization angles~~ PA obtained from the CO ~~tracers~~ different transitions only agreed with each other & ~~with~~ those obtained from dust polarimetry after the ~~circularly polarized~~ CP flux was accounted for. If ARS is common to other objects then using ~~linear polarization~~ LP in CO as a tracer of the magnetic field will ~~have~~ introduce a systematic error unless the ~~circular polarization~~ CP of CO's lines are also measured. The goal of this paper is to show several examples of such circular polarization.

2. MEASUREMENT OF CP WITH RADIO INTERFEROMETRY

The measurement of circular polarization is challenging to calibrate, especially when using radio interferometers like the SMA or ALMA. The SMA polarimeter uses a quarter-waveplate (QWP) to usually convert incident ~~linearly polarized~~ LP light to ~~circularly polarized~~ CP light ~~primarily~~ to measure ~~linear polarization~~ LP signals. While not its ~~intended~~ most common use, at the SMA, the QWP can work the other way to measure CP: incident CP is converted to LP and then measured by the receivers. ALMA on the other hand uses linear feeds and measures the linearly polarized light directly. While both types of feeds can be used to measure ~~circular polarization~~ CP, the calibration process is different Sault et al. (1996). ~~Currently~~ While ALMA does not yet support measuring Stokes V reliably, the SMA has been used to take precise measurements of CP in Sgr A* ~~as reported in~~ (Muñoz et al. (2012)). For a discussion on measuring CP with radio interferometry and on design choices at the SMA (such as the choice of converting from linear- to circular-polarization and vice-versa) see Hamaker et al. (1996); Marrone et al. (2008).

2.1. *Linear vs. Circular Feeds*

To illustrate briefly the differences between the two feed types consider the following: with an orthogonal circular polarization ~~bases,~~ basis the Stokes V parameter for a beam of light is defined by $V = \langle E_L^2 \rangle - \langle E_R^2 \rangle$, where ~~$E$ is the electric field vector and L and R correspond to the orthogonal left-CP and right-CP bases.~~ E_L & E_R are the left- and right-CP electric fields, respectively. With an orthogonal linear ~~bases~~ basis Stokes V is defined by $V = -2\mathrm{Im}(E_x E_y^*)$ where E_x and E_y are the ~~linear bases~~ LP fields. In the ~~circular~~ CP case we take the difference of two measured intensities while the linear feed case requires us to measure the phase of the electromagnetic wave.

Now, when the measurement is made with interferometry it is the visibilities (the correlated waveforms between a pair of antennae) that are measured. In the ~~circular~~ CP case the Stokes V visibility ~~is roughly~~ scales as $\mathcal{V}_V \propto \mathcal{V}_{RR} - \mathcal{V}_{LL}$, where $\mathcal{V}_{RR}$ and $\mathcal{V}_{LL}$ are the visibilities obtained from correlating two antenna measuring right-CP and left-CP, respectively (see eq. (1) below). In the linear feed case the Stokes V visibility is coupled with the Stokes Q and U visibilities (see Section 4.1 of Thompson et al. 2001). This means the Stokes Q and U of any calibration object must be measured as well. This is not possible with the SMA setup used for the observations presented in this paper.

3. SQUINT CORRECTION

~~Here we~~ We now describe spurious Stokes V signals that can ~~arise~~ arise during observations ~~when using the SMA~~ such as those presented here, and our scheme for correcting it. This instrumental Stokes V comes from a slight pointing offset between the left- and right-handed CP beams.

The archival data used was in all cases observed with the goal of measuring ~~linear polarization~~ LP (i.e., the Stokes Q and Stokes U parameters). On the SMA this is done with a quarter-waveplate placed in front of the linear receivers to convert incident ~~circular polarization (CP)~~ LP (CP) to ~~linear polarization~~ CP (LP). While this method suffers from the errors that arise when subtracting two large measurements from each other when performing CP measurements, it avoids having to solve for the ~~linear polarization~~ LP terms of calibration objects when obtaining Stokes V (Marrone et al. 2008; Thompson et al. 2001). Obtaining Stokes V from the visibilities measured with circular feeds is done as follows. paragraph

Given antennae a and b, the Stokes V visibility in the circular feed case is found through (Muñoz et al. 2012):

$$\mathcal{V}_V \simeq \frac{1}{2}\Big\{\mathcal{V}_{RR}/(g_{Ra}g_{Rb}^*) - \mathcal{V}_{LL}/(g_{La}g_{Lb}^*)\Big\}, \qquad (1)$$

where the right-handed CP and left-handed CP visibilities are $\mathcal{V}_{RR}$ and $\mathcal{V}_{LL}$ and are measured by orienting the quarter-waveplate that is placed in the beam of the antennae and correlating the responses of the antennae (Marrone et al. 2008). The complex gain factors for each polarization for each antennae are g_{Ra}, g_{Rb}, g_{La} and g_{Lb} with 'R' and 'L' for right- and left-CP, respectively. Because the Stokes V visibility is found by taking the dif-

The main goal of this paper is to find further evidence of CP in more objects & molecular lines through a search of archival data of the SMA. In Section 2 ...

Be careful here, isn't a visibility the FT of a cross- or auto-correlation? with a mathematical definition this will become clearer (see purple comment at the top of p. 2).

ference of two beams a slight offset gives rise to pairs of positive and negative peaks of Stokes V, as ~~shown in~~ can be seen for example in Figure 1. This offset likely arises because of slight differences in the index of refraction of the quarter-waveplate when it is rotated. ~~but has not been studied with the SMA as far as we know.~~

Because the visibilities are the Fourier transform of the intensity map, an offset in image space is equivalent to a complex factor in visibility space that can be absorbed into the gain coefficients.

Consider a map $I(l,m)$ that represents the true intensity I at angular position l and m. An interferometer samples the Fourier transform of this map $V(u,v) = \int\int e^{-iul} e^{-ivm} I(l,m) dl dm$. make this an equation If the instrument introduces an ~~offset from some unknown position~~ arbitrary offset (l_0, m_0), then the final image we calculate is shifted such that $I'(l,m) = I(l-l_0, m-m_0)$ and the Fourier transform of the shifted map ~~is~~ becomes $V'(u,v) = \int\int e^{-iul} e^{-ivm} I(l-l_0, m-m_0) dl dm$. Changing variables with $\alpha = l - l_0$ and $\delta = m - m_0$ ~~we see~~ move here

use an equation array in latex

$$V'(u,v) = \int\int e^{-iu(\alpha+l_0)} e^{-iv(\delta+m_0)} I(\alpha,\delta) d\alpha d\delta$$

$$\cancel{V'(u,v)} = e^{-iul_0} e^{-ivm_0} \int\int e^{-iu\alpha} e^{-iv\delta} I(\alpha,\delta) d\alpha d\delta$$

$$\cancel{V'(u,v)} = e^{-iul_0} e^{-ivm_0} V(u,v) \equiv g_{\text{offset}} V(u,v) \quad (2)$$

where we used the change of variables...

~~This means that an offset will introduce a complex factor (g_{offset}) to the true visibilities~~. It is therefore easiest to correct for the offset in visibility-space by using *Miriad* (Sault et al. 1995) to solve for the gain coefficients on each beam. Specifically the process is:

1. Observations are calibrated for gain and phase in the usual way using calibration observations of 'good' sources (usually quasars like 3C84, 3C454, etc.) (See Miriad User Guide Sault et al. (2008)).

2. Visibilities are split into line-free continuum data and line data. These are then mapped and used to obtain CLEAN models.

3. The separate continuum and line data are further split into LL and RR visibilities. *Miriad*'s `selfcal` is used on the continuum data to solve for the gain coefficients of each antenna and each polarization (L or R). This is done by minimizing the difference between measured visibilities $\mathcal{V}_{ij}$ of antennae i and j and model visibilities $\hat{\mathcal{V}}_{ij}$ according to $\epsilon^2 = \sum |\mathcal{V}_{ij} - g_i g_j^* \hat{\mathcal{V}}_{ij}|^2$ for each of the correlations LL and RR (Sault et al. 2008; Schwab 1980). The model visibilities used are those found earlier.

4. The gains found from the continuum LL data is then applied to the line LL data, and similarly for the RR continuum and line data.

5. The different visibilities (LL, RR, RL, LR) are recombined and inverted to produce corrected maps. Spectra can be obtained either from the corrected visibilities or the maps.

Figure 1 shows maps before and after this correction is applied for ... → more details on the object used for this example.

4. OBSERVATIONS

We collected radio interferometric polarimetry observations from the Submillimeter Array (SMA) archive that had been measured using the circular feeds, a similar setup to that used by Muñoz et al. (2012) to measure circular polarization in Sgr A*. Because the archival observations were not taken with measurements of circular polarization in mind the SNR is often low, and we had to average velocity channels to increase the SNR at the cost of spectral resolution. This generally increases the SNR from 3-4 to 6-10.

The four objects we present here are Orion KL, NGC7538, IRAS2a in NGC1333 and IRC+10216. The first three are well-known star-formation regions while IRC+10216 is an evolved carbon star. We find significant Stokes V signals in all objects except for NGC1333.

The visibility data are corrected for beam squint, an instrumental artifact that gives rise to spurious Stokes V signals. Squint typically causes distinct pairs of positive and negative peaks of Stokes V throughout the inverted image. Maps are then made of the continuum and lines for each object. The squint correction is confirmed visually by inspecting the Stokes V maps, where we see the pairs of peaks largely disappear. More details on the squint correction will be given in Section 3.

Figure 2 shows corrected Stokes I and Stokes V spectra (left) obtained at the peak of Stokes V on the corresponding maps (right). A comparison of Stokes V spectra before and after correction are shown in Figure 3. Notice in all cases the Stokes V signal decreases after squint correction. Stokes V can also be found in the average of all the visibility data, though the significance is 3-5σ in that case compared to approximately 6-10σ when the spectra is taken from the inverted maps. This indicates the detections are not simply the result of the inversion process that creates the maps. We present here only the map spectra. In general the peaks of Stokes I and Stokes V are not at the same map position.

In Orion KL the lines of CO ($J = 3 \rightarrow 2$ at 345.8GHz) and SiO ($J = 8 \rightarrow 7$ at 347.3GHz) are both bright (peak Stokes I of around 20 Jy/beam and 55 Jy/beam respectively; not shown) and both show Stokes V signals. The CO Stokes V signal has an antisymmetric structure

We thus find the aforementioned complex offset that multiplies the visibility.

You seem to be using a new notation here.