Report on MN-18-1764-MJ

July 11, 2018

Dear Editor,

We are grateful to the referee for the helpful recommendations and comments. The paper has been revised to address all points. Below are the referee's comments (in quotes) followed after each point by our response in bold. We have also attached a PDF with all the changes colored in olive-green and underlined.

Sincerely,

M. A. Chamma, M. Houde, J. M. Girart, and R. Rao

Assistant Editor's Comments

"Please ensure that all textual labels in figures are at least as large as the caption text; any smaller and they become too difficult to read."

Response:

Most figure and axes labels are now larger

Reviewer's Comments

Comment 1:

"The paper is well argued, and shows a plausible explanation for non-Zeeman circular polarization found in molecular spectra. I set out below some recommendations that I believe would improve the paper.

Introduction, p1, end of 1st column: It would probably be useful to just add a few lines of explanation about the GK effect. It appears to be transfer of polarized radiation through a Zeeman-split medium in the case where the Zeeman splitting frequency is larger than the rate of all processes except the Doppler width of the spectral line.

A statement similar to the above would make the paper more self-contained, and only the more interested reader would need to look up the original GK paper."

Response:

We've added the following explanation of GK in the introduction:

The GK effect can occur for molecular lines with even weak Zeeman splitting when the radiation field (for example) is anisotropic and the splitting frequency is greater than the collisional rate and other radiative processes. These conditions can cause a population imbalance in the magnetic sublevels that results in a net LP aligned either perpendicular or parallel to the plane-of-the-sky component of the magnetic field.

Comment 2: Section 2

"Obviously, at the frequencies considered in the manuscript, one's choice of telescope is very limited, and it is rather unfortunate for this work that both the SMA and ALMA are equiped with linear feeds. If the authors are aware of any similar observations, probably at lower frequencies, where additional non-Zeeman circular polarization profiles and/or images have been obtained with telescopes equiped with circular feeds, I feel that a reference to that work would add considerable weight to the argument, since the calibration process is much less replete with sources of error."

Response:

While there seem to be several VLA and VLBA observations of CP we believe the most relevant work is that by Cotton et al. 2011 using the VLBA. The VLBA is equipped with off-axis circular feeds and they used a very similar squint correction as the one we detail. We've added a paragraph to the ends of Section 2 and Section 5.1 to highlight this. Other relevant observations (like Hezareh et al. 2013) used linear feeds.

Comment 3: Definition of Stokes-V

"On line 4 of Section 2.1, Stokes V is written as 'left'-'right'. However, in the next paragraph, and in eq.(3), it is 'right'-'left'. I recommend that Stokes definitions should conform to the IAU standard of 'right'-'left' in all cases. The IAU definition also appears to agree with the definition of Stokes V as -2Im{E_x E_y^*} in the first paragraph of 2.1."

Response:

Changed Section 2.1 to conform to the IAU standard (right - left)

Comment 4: Additional Calibration Information

"It is surprising that, for linear feed instruments, no mention is made of the correction for the parallactic angle. Obviously, this does not matter for true circular feeds, but it is not clear to me whether the 1/4 and 1/2-wave plate equipment used in the SMA linear feeds is insensitive to the parallactic angle."

Response:

The SMA observes point sources over a large range of parallactic angles to correct for it and to obtain the polarization leakages, however Stokes I and V are independent of the leakages to first-order. We've added the following paragraph at the end of section 2.1 to explain this. As an aside the SMA only uses QWPs and has no half-wave plates.

The SMA uses observations of a bright point source over a large range of parallactic angles to distinguish between source and instrumental polarization and determine the polarization leakage terms. Determining these leakage terms is crucial for accurate Stokes Q and U measurements, however Stokes I and V are independent of the leakage terms to first-order (Thompson et al. 2001; Marrone et al. 2008; Muñoz et al. 2012).

Comment 5:

"Secondly, the intensity function in eq.(2) is the 'dirty' map, that is it is the true source intensity convolved with the instrumental beam. In a polarization observation there are slightly different (in general) beams for each hand of circular polarization, or each Stokes parameter. In AIPS, they have the file extensions, LBEAM, RBEAM, QBEAM, VBEAM etc. Were the Stokes-I and Stokes-V maps deconvolved with a model based on their own beam, or just Stokes-I? Which algorithm was used for cleaning by Miriad: Clean or maximum entropy?"

Response:

We've added a clarification after eq. 2 to highlight that $I(l, m)$ is convolved with the instrumenal beam. In regards to the deconvolution we use the CLEAN algorithm and Miriad produces only a single beam for all polarizations. We checked that the instrumental beams for the LL and RR polarizations were not very different from each other by 'forcing' Miriad to invert each set of data seperately. The beams had very slight differences in their RMS but the shape of both beams were essentially identical. We've added the following paragraph towards the end of section 3 to explains this:

Note that in the deconvolution steps (steps 2 and 5) the same instrumental beam is used for all polarizations. This is due to the behaviour of Miriad 's invert, which produces a single instrumental beam corresponding to all image planes and Stokes parameters (sec. 13.4 of Sault et al. 2008). We checked that the instrumental response to different polarizations was similar by inverting the LL- and RR-handed visibilities separately from one other and finding that the instrumental beams for both polarizations to be almost identical.

Step (2) of Section 3 also clarifies that the CLEAN algorithm is used.

Comment 6: Observations

"1st para., l3: SMA data is described as having been measured using circular feeds. However, in the previous section, the SMA has been described as an instrument with linear feeds. It would be better to say that the data was obtained with the linear to circular wave-plate equipment installed."

Response:

We've replaced the offending line at the beginning of Section 4 concerning the SMA feeds with your suggestion.

Comment 7:

"Caption to Fig. 2: In the spectra, the Stokes-V lines are purple, not blue.

[Blue is correct for the maps]."

Response:

Purple lines are now blue, thank you!

Comment 8: Section 5.2

"As for the GK mechanism, I feel that this Section is missing a good basic physical description of ARS. The reader of a more mathematical bent should not be denied equations 5-10, but these formulae are just results that, in my opinion, convey almost nothing about the process itself. Of course, the reader may just wish to launch into the 2013 paper, but I think a short physical description would be very helpful. My attempt follows: ARS is a matter-radiation interaction mechanism mediated by the second-order diagonal elements of the molecular density matrix (rather than the much weaker first-order off-diagonal elements). In the presence of a magnetic field, a small phase-change may be propagated at each scattering between the n-photon states of incident radiation that are linearly polarized parallel to, and perpendicular to, the magnetic field. This phase change leads to the appearance of circular polarization in the scattered radiation."

Response:

We've added the following paragraph to 5.2 to explain the physical basis for ARS:

ARS rests on a second-order interaction between radiation and matter in the presence of a magnetic field. Incident radiation with photon states polarized $\|$ and $\perp$ to the magnetic field can scatter slightly differently off a molecule and incur a small phase shift between the photon states. The phase shift incurred after propagating and scattering off many molecules results in the appearance of CP in the scattered radiation.

In addition to the above changes the abstract has been modified slightly, an acknowledgements section has been added, as well as urls to to the scripts used for the reduction and squint correction.