Alignment of Magnetic Fields and Gas Structures in the Orion A Cloud

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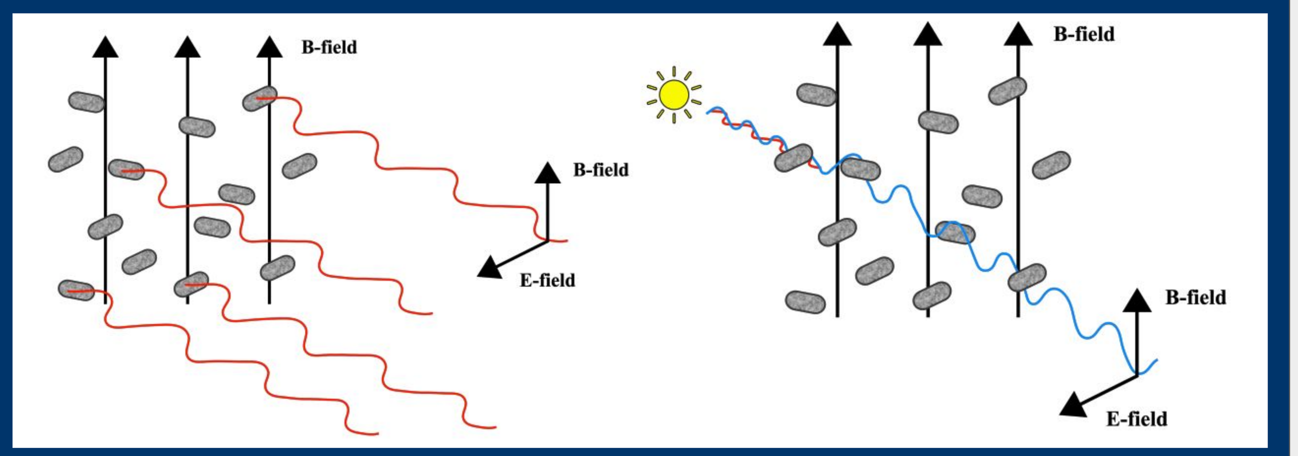
SIGNIFICANCE

The Orion A molecular cloud is one of the closest active star forming regions at around 400 parsecs away from the Sun. The region contains many distinct regions of star formation and molecular gas components, which in addition to its vast array of observations and previous works, **provides an excellent laboratory in studying the role of magnetic fields in varying environments of star forming regions.**

Magnetic fields play an important role in the formation and evolution of molecular clouds and interstellar gas, and in turn star formation.

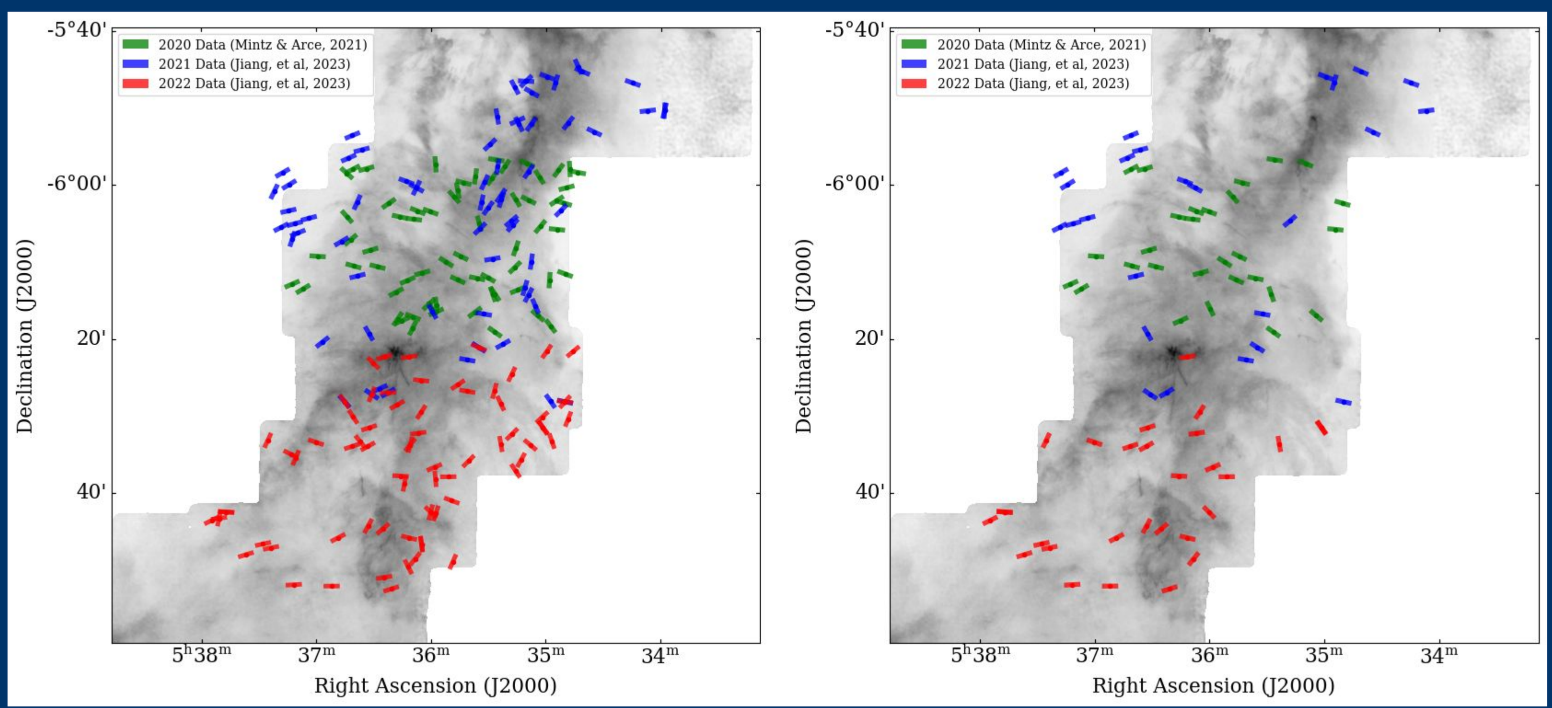
Magnetic fields are believed to **BOTH** inhibit star formation by countering the collapse of gas and help produce dense, active star-forming structures by funneling material from diffused regions into higher-density regions like filaments. Recent work exploring magnetic fields in filaments have found that magnetic fields can affect turbulence and shock behavior and direct the flow of gas.



METHODS

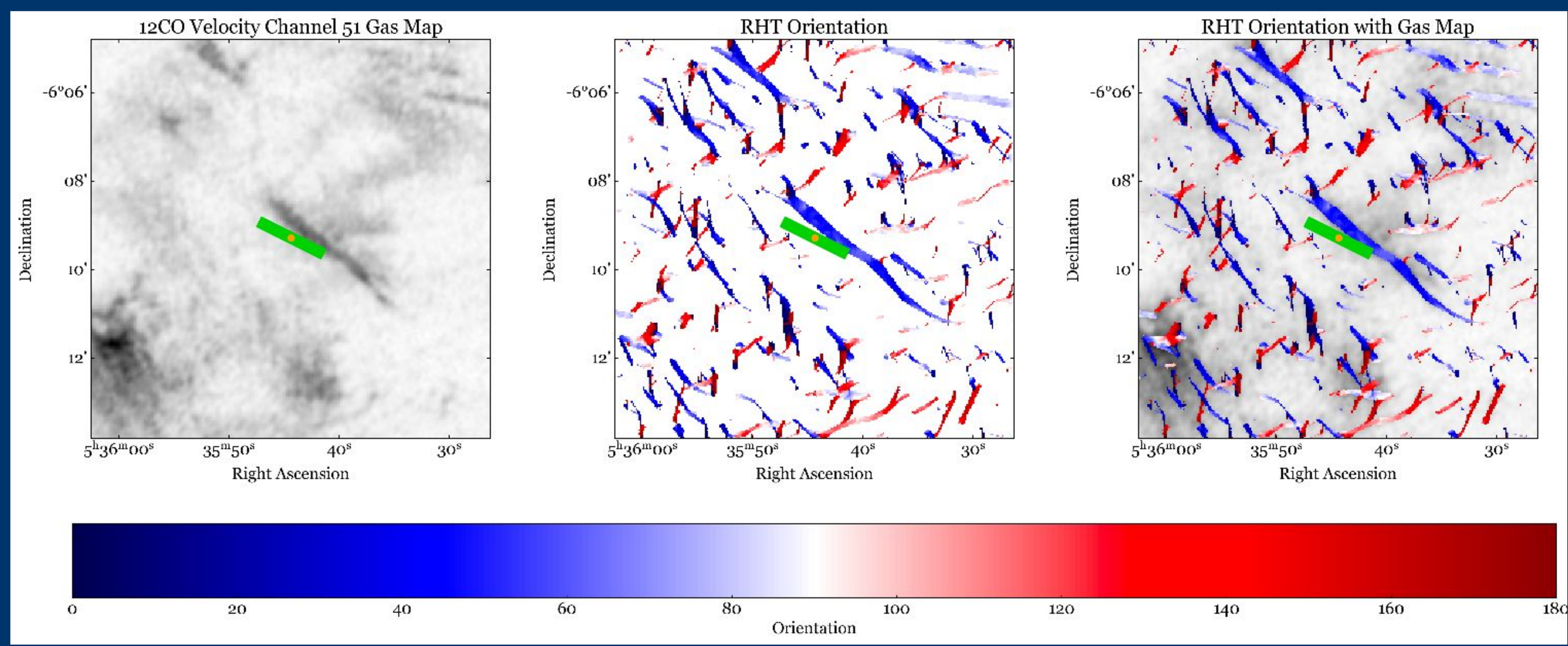
Orientation of Magnetic Fields in Diffused Regions

We used the WIRC+Pol Spectropolarimeter on Palomar Observatory Hale Telescope, to measure H-band extinction polarization vectors in diffused regions of Orion A. We measure starlight polarization for bright H-band stars within and background to the cloud. We observed about 202 stars (Left) over three years (2020–2022). We then ensure our stars are polarized (P* > 0) and the signal to noise is greater than 2 for the polarization measurement (P*/sigP>2), leaving us with 82 stars (Right).



Orientation of Gas Structures in Orion A (RHT)

To compare the gas structures to the orientation of the magnetic field around each source, we make use of the Rolling Hough Transform (RHT) Algorithm, a machine vision algorithm that searches for linear structures in images. For each source, we create a 9x9 arcmin cutout of the gas map (Left). We then run the RHT on each of the velocity channels of the 12CO, 13CO, and C18O gas maps for the 31 velocity channels (0.25 km/s per channel) with emission close to the central cloud velocity which encompasses both low, medium, and high-velocity gas in Orion A (V_lsr ≈ 6 km/s to 13 km/s).



Alignment of Magnetic Fields and Gas Structure across Velocity

For each 9x9 arcmin image, we then calculate the alignment between the source's magnetic field orientation and the orientation of all the structures in the image. We calculate an angular difference, and then an alignment term. We use a value from -1 to 1 for alignment, where -1 is misaligned or perpendicular and 1 is aligned or parallel. We use this variable in order to ensure that 0 degrees and 180 degrees are treated as the same, as to match the IAU polarization convention.

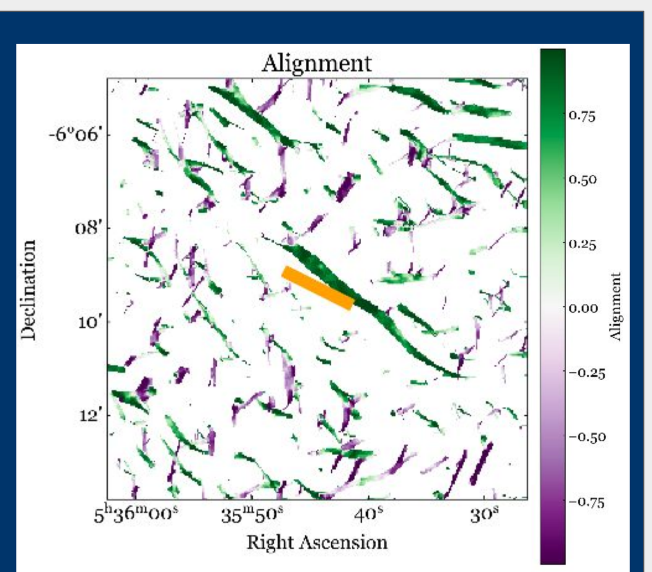
To calculate this alignment term, we first calculate an angular difference term which measures the difference between two angles:

$$\delta\theta = \frac{1}{2}tan^{-1}\left(\frac{sin(2\theta_{gas})cos(2\theta_{BPOS}) - cos(2\theta_{gas})sin(2\theta_{BPOS})}{cos(2\theta_{gas})cos(2\theta_{BPOS}) + sin(2\theta_{gas})sin(2\theta_{BPOS})}\right)$$

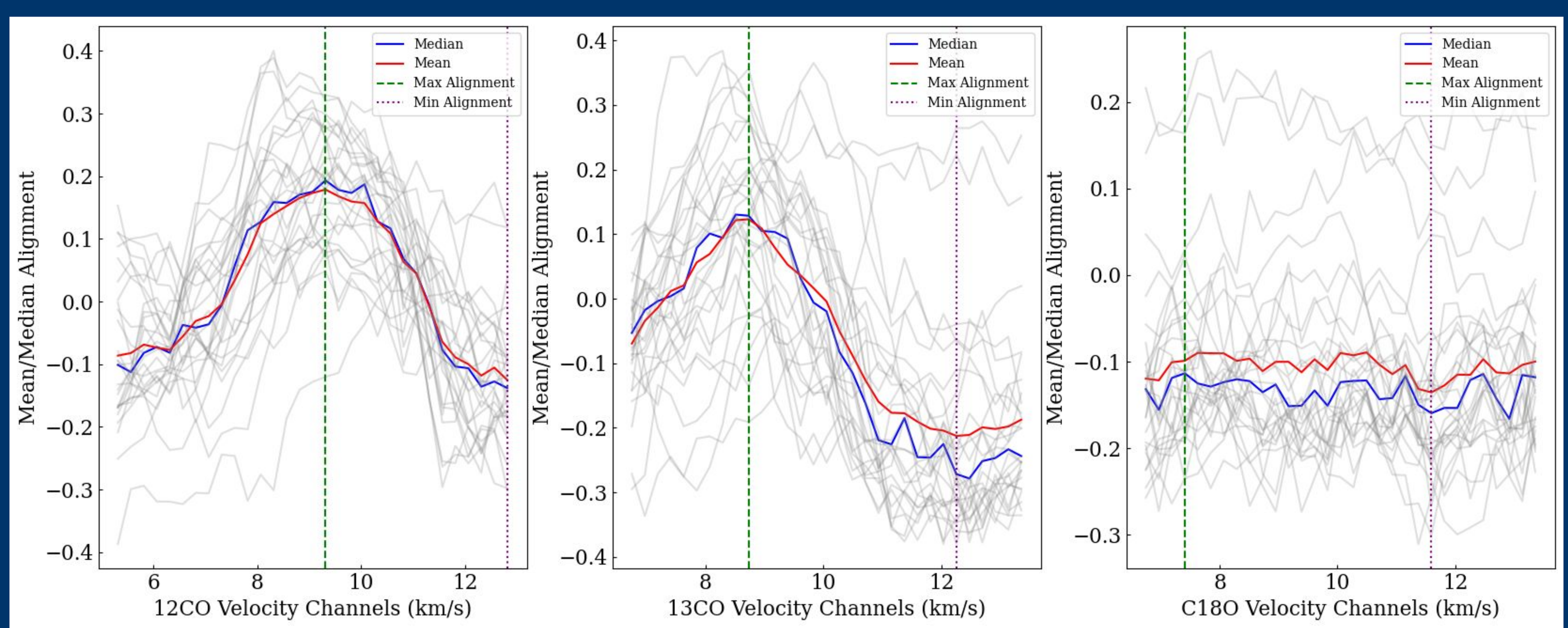
From the angular difference term, we can then calculate the alignment term:

$$\xi = \langle cos(2\delta\theta)\rangle$$

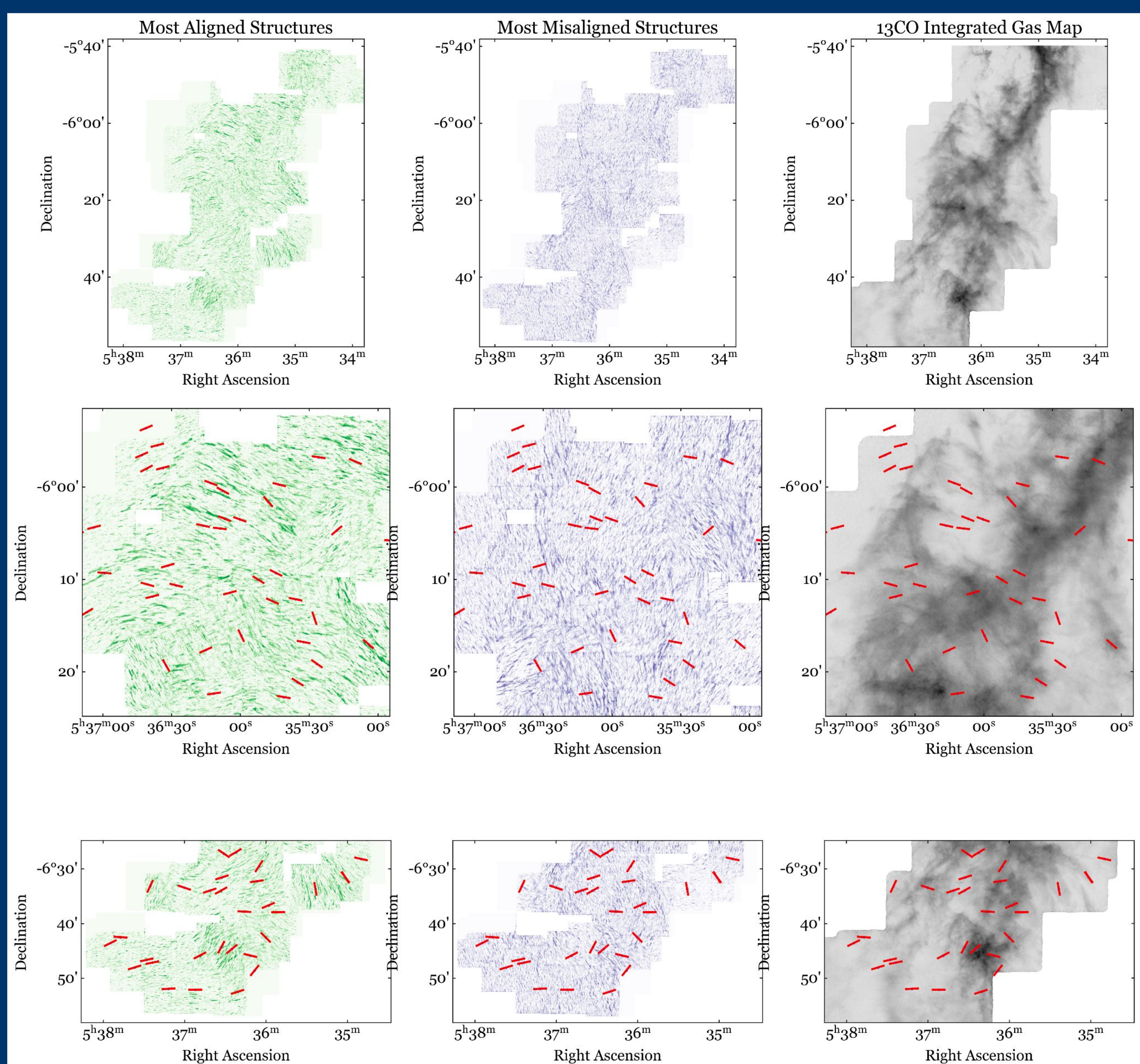
For RHT orientation image, we then calculate the pixel-by-pixel alignment of the RHT gas orientation with the magnetic field orientation from the starlight polarization. In the end, we produce an alignment map, as shown in the Figure on the left, for each source at all 31 velocity channel in the 12CO, 13CO, and C18O gas maps.



RESULTS



We can calculate the average alignment of the image for each velocity channel map, for 12CO, 13CO, and C18O.. The above figure shows the average alignment as a function of velocity for each of the gas maps for every source (gray lines). We find that on average 12CO and 13CO gas seem to have high and low alignment around the same velocity near 9 km/s and 12 km/s, respectively. For C18O, we find that structures are, on average, more misaligned than aligned to the magnetic field across all velocity channels.



We can then take the alignment image and extract out only the most aligned and misaligned structures across all velocity channels. All these images can then be stacked together to create a larger map and compared to the original integrated intensity map. The figure above shows the aligned and misaligned structures for the 13CO gas V_lsr ~ 6 km/s to 13 km/s obtained from comparing the magnetic field orientation from starlight polarization and the gas orientation from RHT

SUMMARY

To summarize, we:

1. Present new H-band starlight polarization from WIRC+Pol taken in the diffused regions of Orion A to study the magnetic field
2. We find that the polarization angle dispersion is only 22 deg., which implies that the plane-of-the-sky magnetic field strength is fairly strong in this region.
3. Gas Structures found in the outskirts of the cloud (traced by 12CO and 13CO) in Orion tend to be more aligned with the magnetic field than that of denser inner regions (traced by C18O)
4. We find that the starlight polarization derived magnetic field tends to show a preferential east-west direction, which matches with the magnetic field found in dust emission from Planck observations

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