Brief report of CN 1-0 observations with IRAM-Xpol (project 150-15)

Summary: Stokes V signal is contaminated by I total power at a very problematic level hampering any reasonable Zeeman measurement. The leakage is between 0.9 and 1.4% depending on the observed position and possibly on the source elevation.

Context: Alizée Duthu, my Ph-D student, went observing for her project 150-15 last March (project rated B) during one entire week (around 40 hours of observing time) using Xpol at 3mm. The goal was to map the magnetic field along the CN ring of IRC+10216. We used the CN 1-0 hyperfine lines and thanks to the Zeeman effect (applying Crutcher method) we were hoping to estimate B (on the line-of-sight) from the Stokes V signal.
The careful data reduction we made during the past weeks has shown that there is a huge I-> V leakage hence a strong contamination of the V signal, spoiling any real Zeeman signature in the V spectra…

A- Description of the observations

The four Stokes parameters of each CN hyperfine component are covered simultaneously with a single VESPA setup comprising two sections (see Fig. 1 and Table 1), V01 (lines 1-3) and V02 (lines 4-7), respectively of 160 and 80 MHz width.

(N', J', F') → (N, J, F)	ν_0 (GHZ)	Z (Hz .μG^{-1})	R.I.	$Z \times R.I.$
1. (1, 1/2, 1/2) → (0, 1/2, 3/2)	113.14434	2.18	8	17.4
2. (1, 1/2, 3/2) → (0, 1/2, 1/2)	113.17087	-0.31	8	2.5
3. (1, 1/2, 3/2) → (0, 1/2, 3/2)	113.19133	0.62	10	6.2
4. (1, 3/2, 3/2) → (0, 1/2, 1/2)	113.48839	2.18	10	21.8
5. (1, 3/2, 5/2) → (0, 1/2, 3/2)	113.49115	0.56	27	15.1
6. (1, 3/2, 1/2) → (0, 1/2, 1/2)	113.49972	0.62	8	5.0
7. (1, 3/2, 3/2) → (0, 1/2, 3/2)	113.50906	1.62	8	13.0

Table 1: Zeeman Splittings for CN N=1-0 (Crutcher et al.1996). R.I. stands for Relative Intensity in LTE conditions.

The adopted backend and receiver configurations were:

```
BACKEND VESPA 1   0.080   80     +158.0  /receiver e0 h ui /mode polar  !line CNup
BACKEND VESPA 2   0.080   160    -172.0  /receiver e0 h ui /mode polar  !line CNlow

receiver E090 CN(1-0)    113.34   UI  /eff 0.95 0.81 /hor UI  /vertical UI /tempload 77 L
```

To correct for the resulting contamination of the intrinsic Stokes V signal, we use the achromatic nature across the hyperfine components of a given CN transition (Crutcher et al. 1996), but also we use a map of the instrumental polarization as measured on a planet (Wiesemeyer et al. 2014): in March 2016, we have done a 2'x2' map of Jupiter at 40° and 59° of elevation (instrument polarization depends on the elevation).

B- Original spectra and Estimate of the leakage/contamination

Following this observing procedure, we get “VO1” and “VO2” VESPA spectra, respectively for sets of CN lines 1-3 and 4-7.

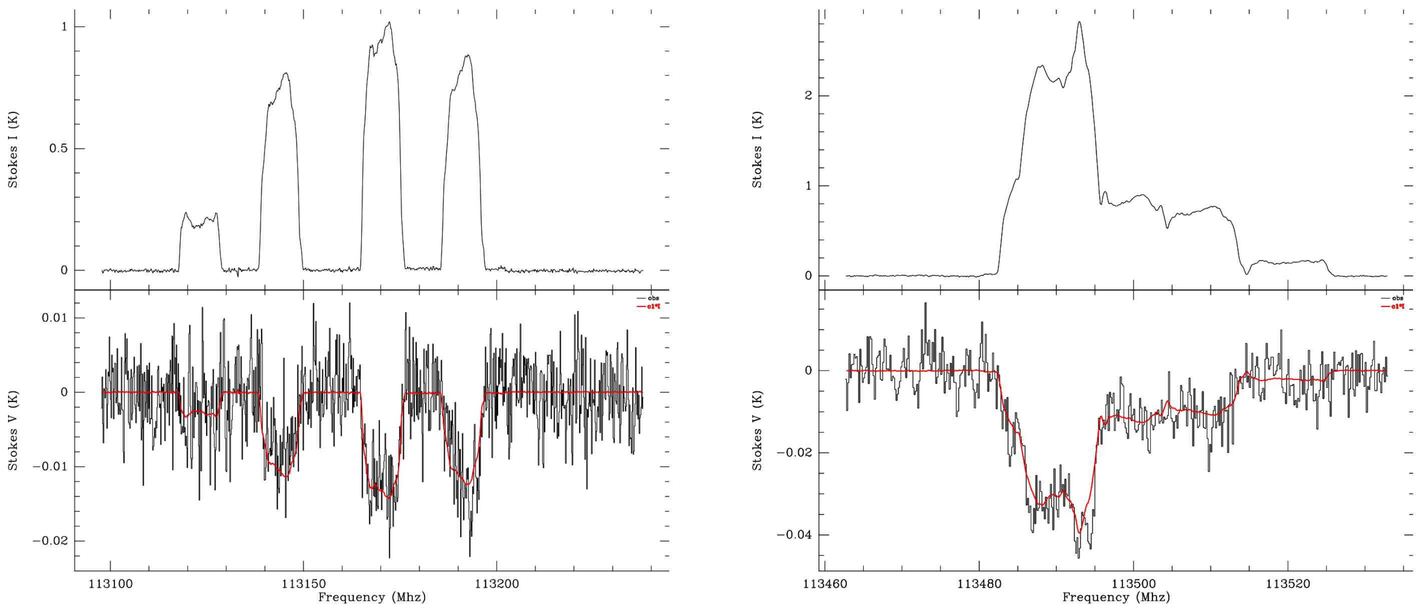

Fig.1: March 2016.observations. *Left*: CN (1,1/2) → (0,1/2) Stokes I (Top) and V (Bottom) spectra for IRC+10216 for the position (+18", -04"). *Right*: same for the CN transition (1,3/2) → (0,1/2). Observation and least-squares fits for V are respectively in black and red.

An example of I and V spectra for one position (+18",-04") is given in Fig.1. In this observation from March 2016 we clearly see that the V profile is a mirror of I spectra. For comparison, we show below (Fig.2) what we observed (for position -10",+20") in 2006 towards the same source: no copy of I into V is observed.

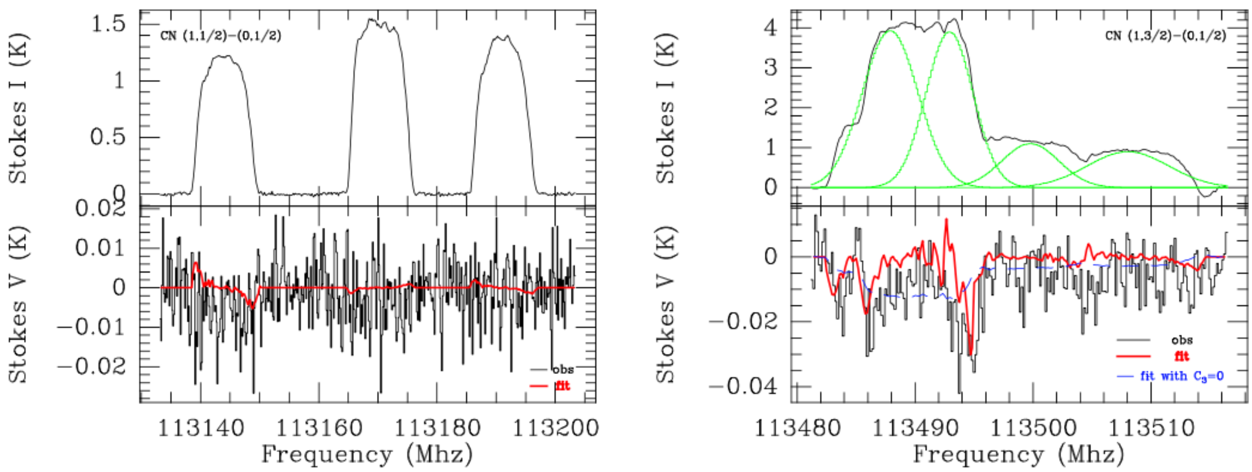

Fig.2: 2006 observations. *Left*: CN (1,1/2) → (0,1/2) Stokes I (Top) and V (Bottom) spectra for IRC +10216 for the position (-10", +20"). *Right*: same for the CN transition (1,3/2) → (0,1/2). Observation and least-squares fits for V are respectively in black and red.

Between the two periods, 3mm mixers have been changed: the receiver has now one single horn.

Applying Crutcher method, we tried to fit the V spectra (for each *i* component) with the following formula:

$V_i(\nu) = C_1 I_i(\nu) + C_2 dI_i(\nu)/d\nu + C_3 Z dI_i(\nu)/d\nu$

where C_1 is the gain difference in the telescope between the right and left circular polarizations, i.e. the I into V leakage, and C_2 is the beam squint. The magnetic field is determine by C_3 = B/2.

Because we now have one single horn for the two polarizations, the beam squint has disappeared and C_2 is then equal to zero. We first estimate the leakage C_1, then C_3.

For the different observed positions we derive:

<u>- position 0 0 :</u>
c1= 0,009, then V= 0.9%I
<u>- position -18 -10 :</u>
c1= 0,011, then V= 1.1%I
<u>- position -18 +10 :</u>
c1= 0,012, then V= 1.2%I
<u>- position +18 -04 :</u>
c1= 0,014, then V= 1.4%I
<u>- position +20 +16 :</u>
c1= 0,0125, then V= 1.25%I

Hence the leakage is between 0.9 and 1.4 % depending of the observed positions.

In addition, we have tried to check any dependance of the leakage with the source elevation. One positions has been actually observed at average elevation of 60° and 53° (two different nights, roughly same weather conditions). We find c1= 1.3 and 1.1% respectively at 60 and 53°. We are currently investigating other cases and it seems there is a possible elevation dependance.

C- Analysis of the "true" V signal.

Now that the leakage has been estimated, we subtract it from the V signal in order to get the "true" V signal. Hence we get:

$V_i(\nu) - C_1 I_i(\nu) = C_3 Z dI_i(\nu)/d\nu$ = Vtrue

The resulting Vtrue spectra are very noisy. The estimated rms is then 5-8 mK at 0.2 km/s resolution, for an integration time of 110-156 minutes.

On figure 3 is shown the residual, hence the true V signal, for still the same position (+18",-04").

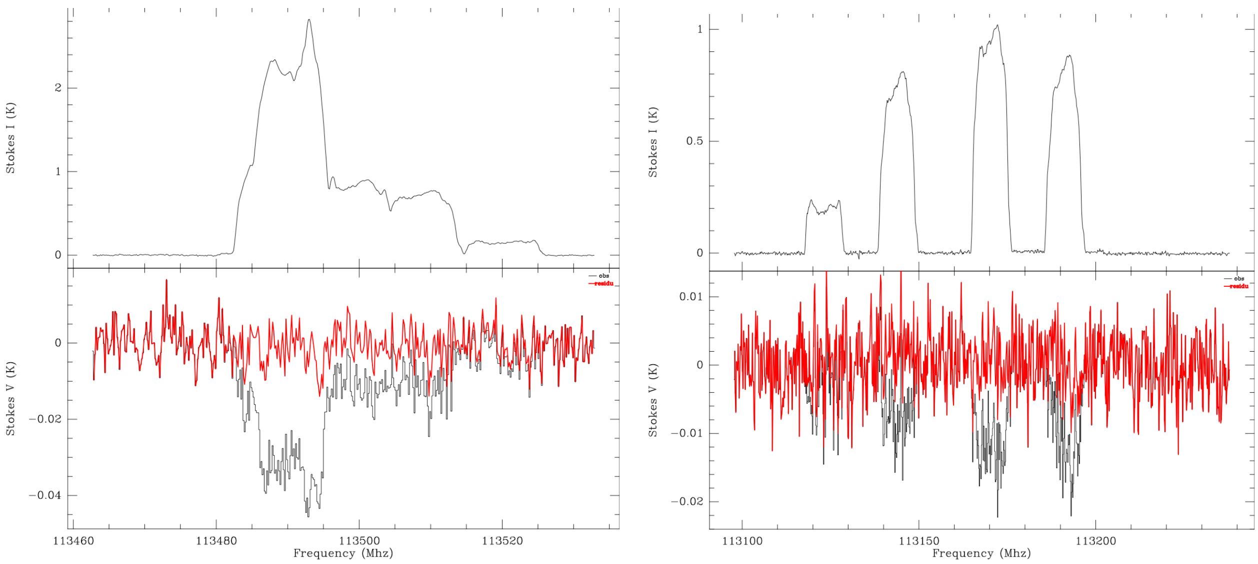

Fig.3: in red the "true" V signal, i.e. observed V-leakage.

Then, we try to fit the true V signal with $C_3\, Z\, dI_i(v)/dv$ and to estimate the B strength (see Fig. 4).

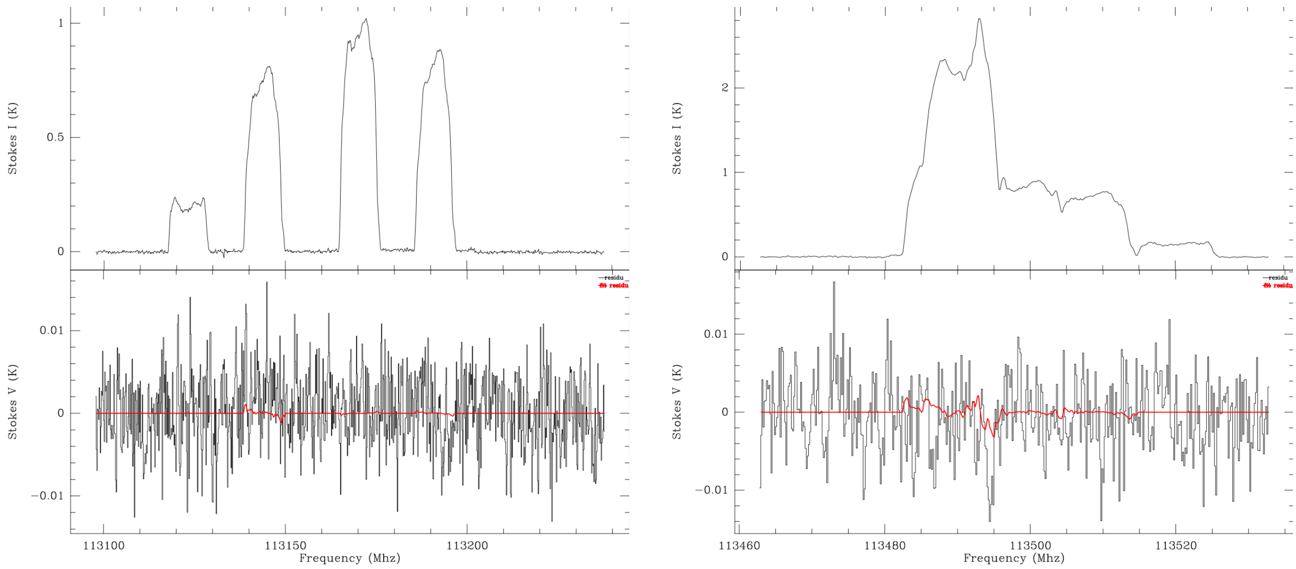

Fig. 4: *Left*: CN (1,1/2) → (0,1/2) Stokes I (Top) and true V (Bottom) spectra for IRC+10216 for the position (+18”, -04”). *Right*: same for the CN transition (1,3/2) → (0,1/2). Crutcher's V fit is in red.

You can see that a weak Zeeman pattern is detected for position +18, -04. But the signal is very weak. We are able to estimate C3 to roughly 1500 everywhere, corresponding to B=3mG, but the uncertainty is huge, more than 100% !! Let’s say that we only derive an order of magnitude.

D- Conclusions

Stokes V signal is contaminated by I total power at a very problematic level hampering any reasonable Zeeman measurement. The leakage is between 0.9 and 1.4% depending on the observed position and possibly on the source elevation. As the 1 and 2mm have not been changed, this leakage should only affect the 3mm observations.

We thus propose to perform the polarimetric study in CN 2-1 at 1 mm. According to Bachiller et al. (1997), the CN 2-1 lines should be of the same intensity or even slightly stronger than the 1-0 lines.