Non-Zeeman Circular Polarization of Rotational Molecular Spectral Lines

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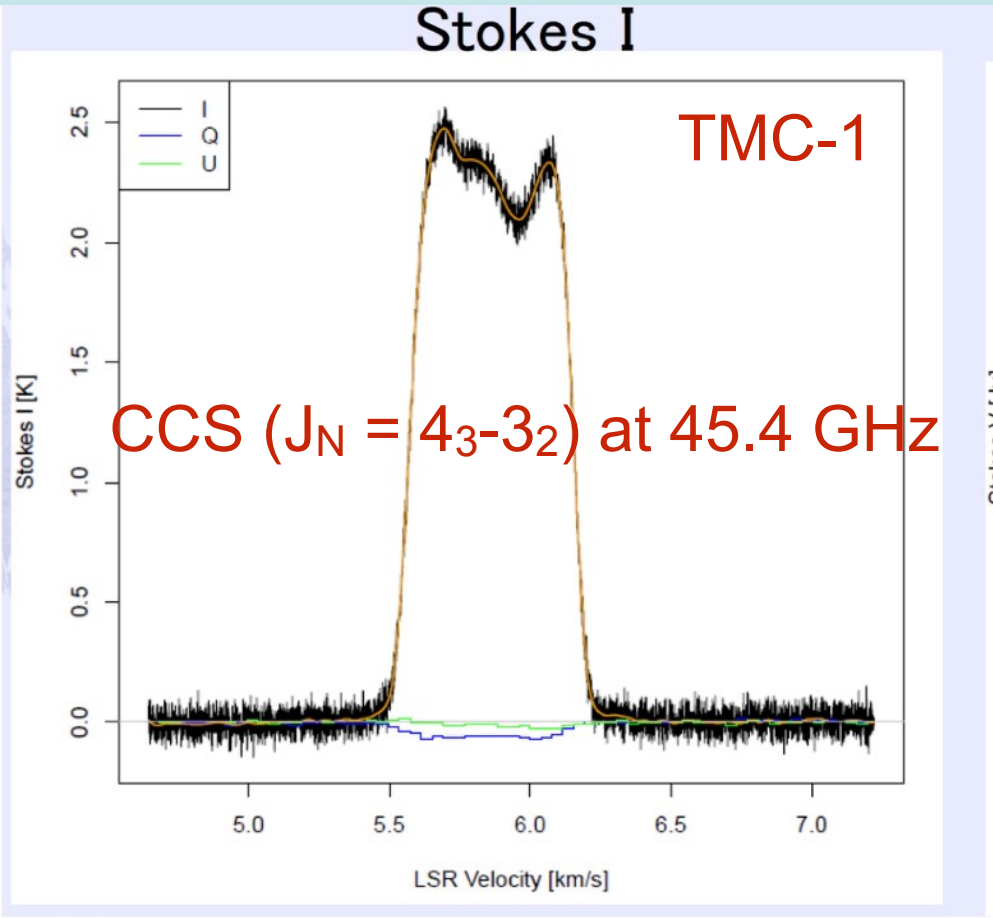
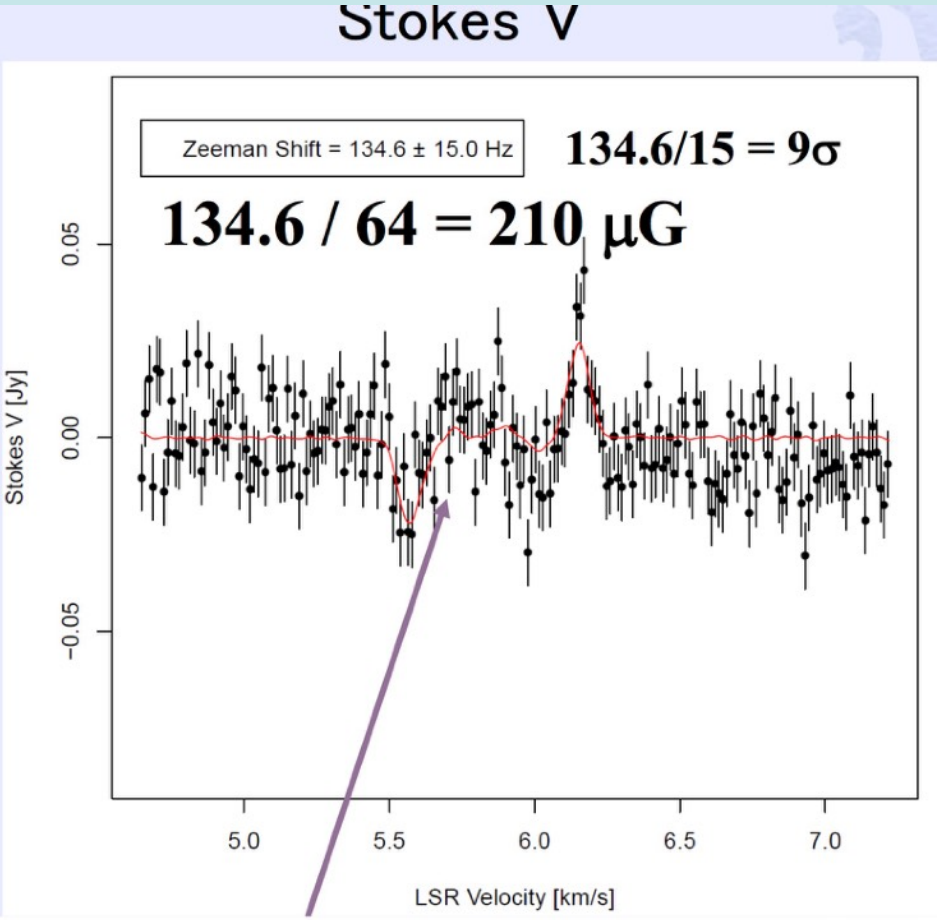
Outline

- This talk is about Magnetic Fields and their interaction with molecules
- Linear Polarization Measurements of Molecular Spectral Lines
  - Goldreich-Kylafis Effect (linear polarization)
- Circular Polarization Measurements of Molecular Spectral Lines
  - Orion KL (FSPPol/CSO)
  - Physical Model
  - SNR IC 443(G) (IRAM 30m)
  - OMC-2 FIR 4 (FSPPol/CSO)
  - SMA results
  - SiO masers (IK Tau/VLBA)

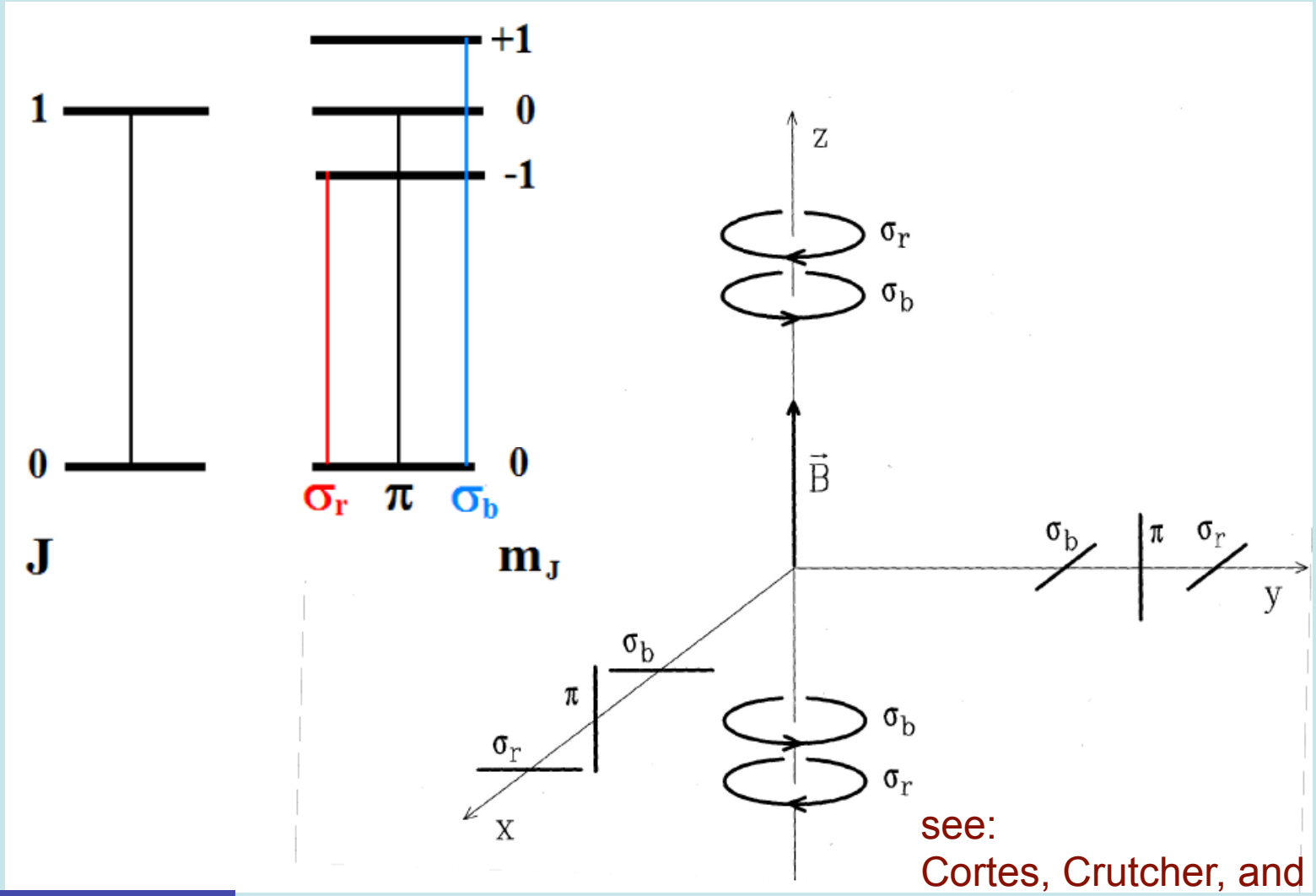
News from the Zeeman World…





Nakamura+ 2015, PASJ, 67 (6), 117

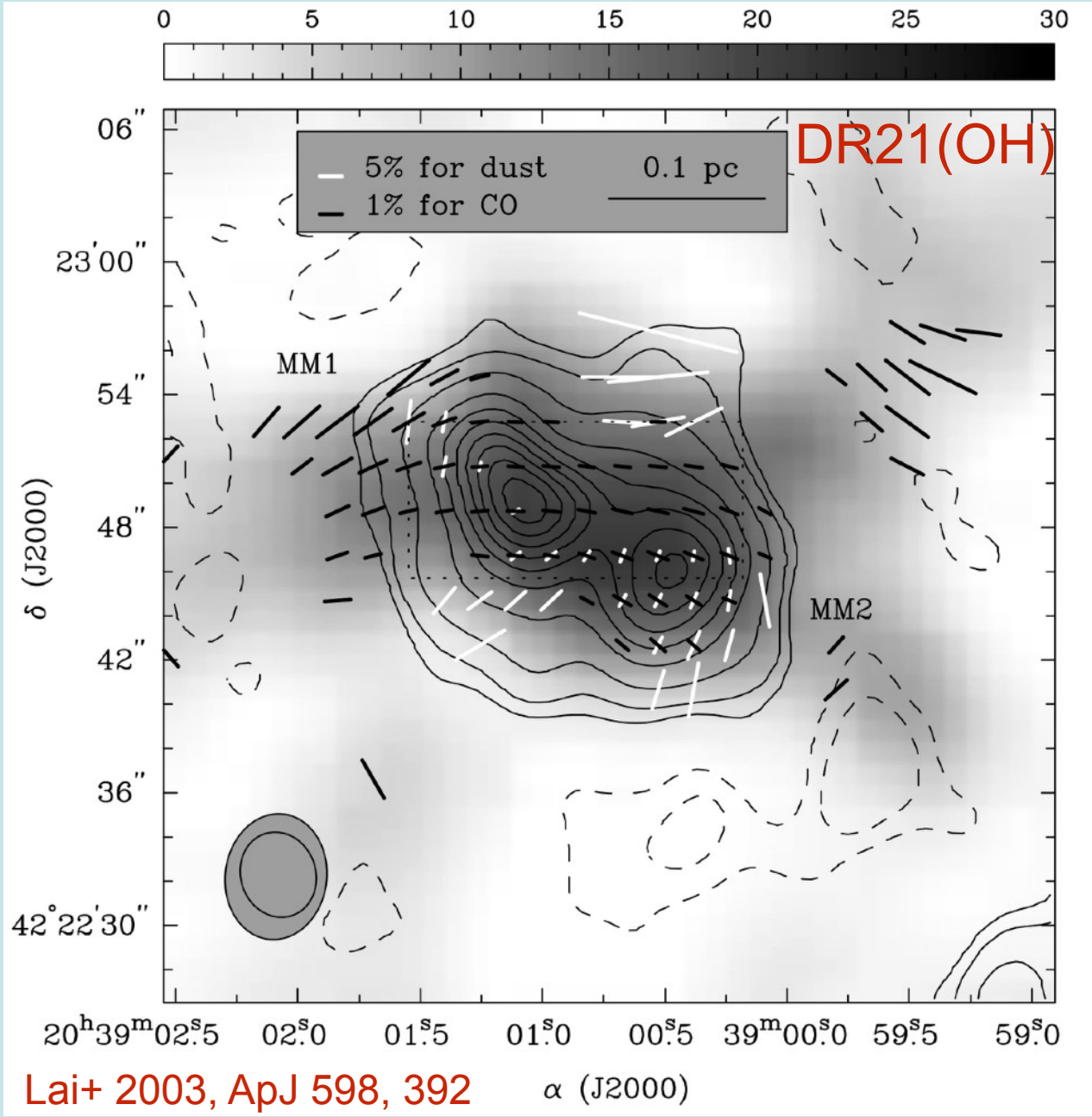
Linear Polarization of Molecular Lines - Goldreich-Kylafis Effect



see:
Cortes, Crutcher, and Watson 2005, ApJ, 628, 780

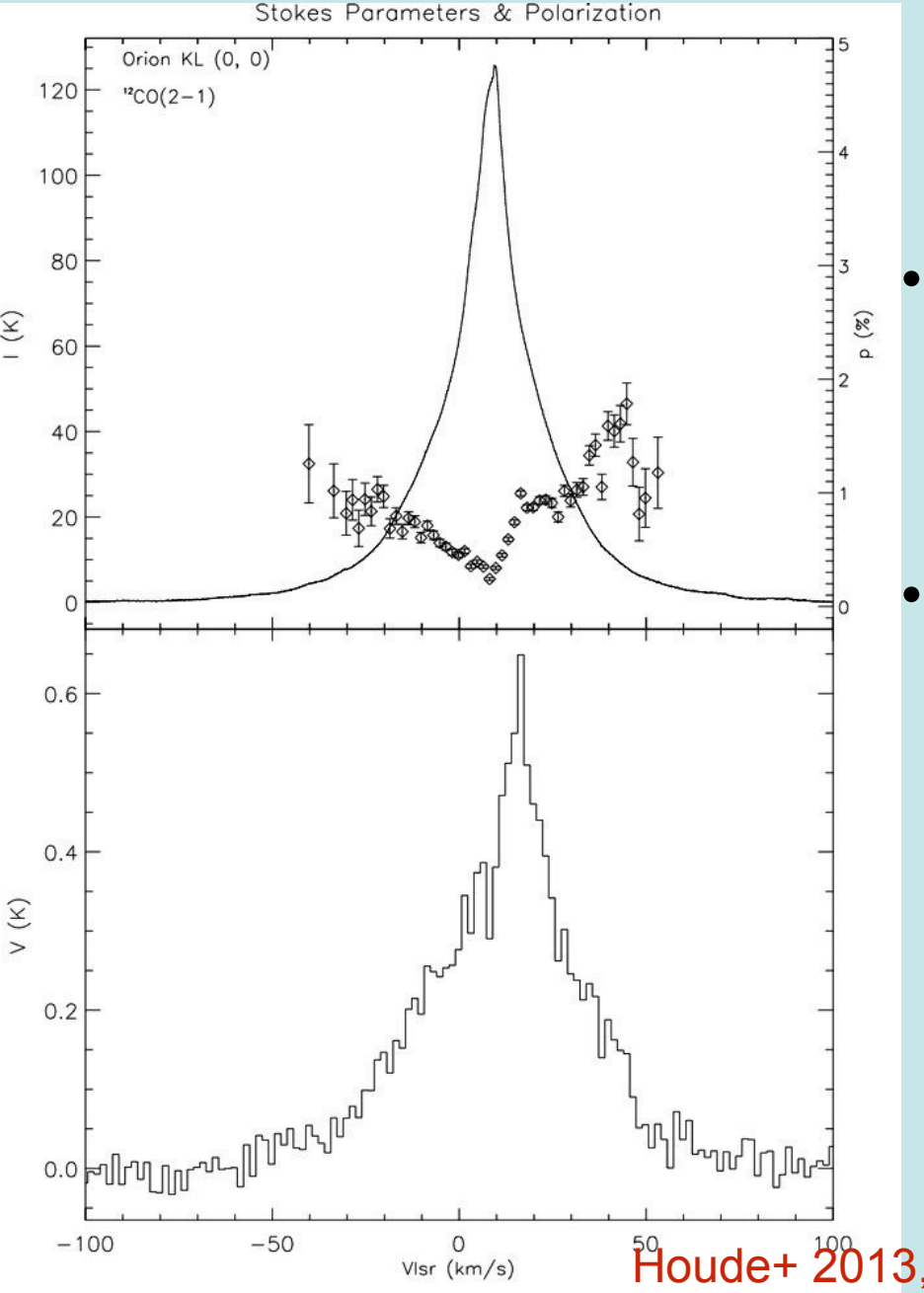
Goldreich-Kylafis (CO Linear Polarization)

- Complementary to dust polarization
- E.g., can be use to trace outflows
- GK effect has a 90 deg ambiguity…
- **We understand molecules better than dust**
- but there's a complication (opportunity)…



Lai+ 2003, ApJ 598, 392

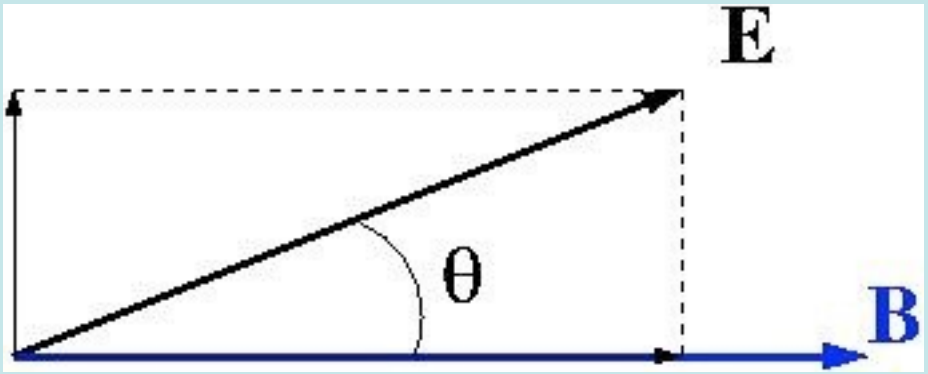
CSO / FSPPol - CP Measurements



- Circular polarization measurements in Orion KL of the $^{12}C^{16}O\ (J = 2 \rightarrow 1)$ rotational line at 230.5 GHz with FSPPol
- Zeeman splitting ~ 0.2 mHz/μG
  - ~4 orders of magnitude less than CN

Houde+ 2013, ApJ, 764, 24

Anisotropic Resonant Scattering



Radiation State of LP at angle θ

$$|\theta\rangle = \alpha|\|\rangle + \beta|\perp\rangle$$

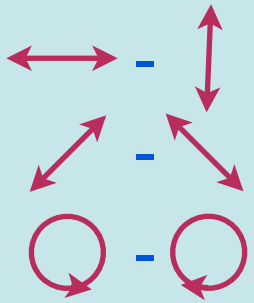
with $\alpha = \cos(\theta), \beta = \sin(\theta)$

$$|\theta'\rangle \simeq \alpha e^{-i\phi}|\|\rangle + \beta|\perp\rangle$$

$$Q = Q_0$$

$$U = U_0 \cos(\phi)$$

$$V = U_0 \sin(\phi)$$

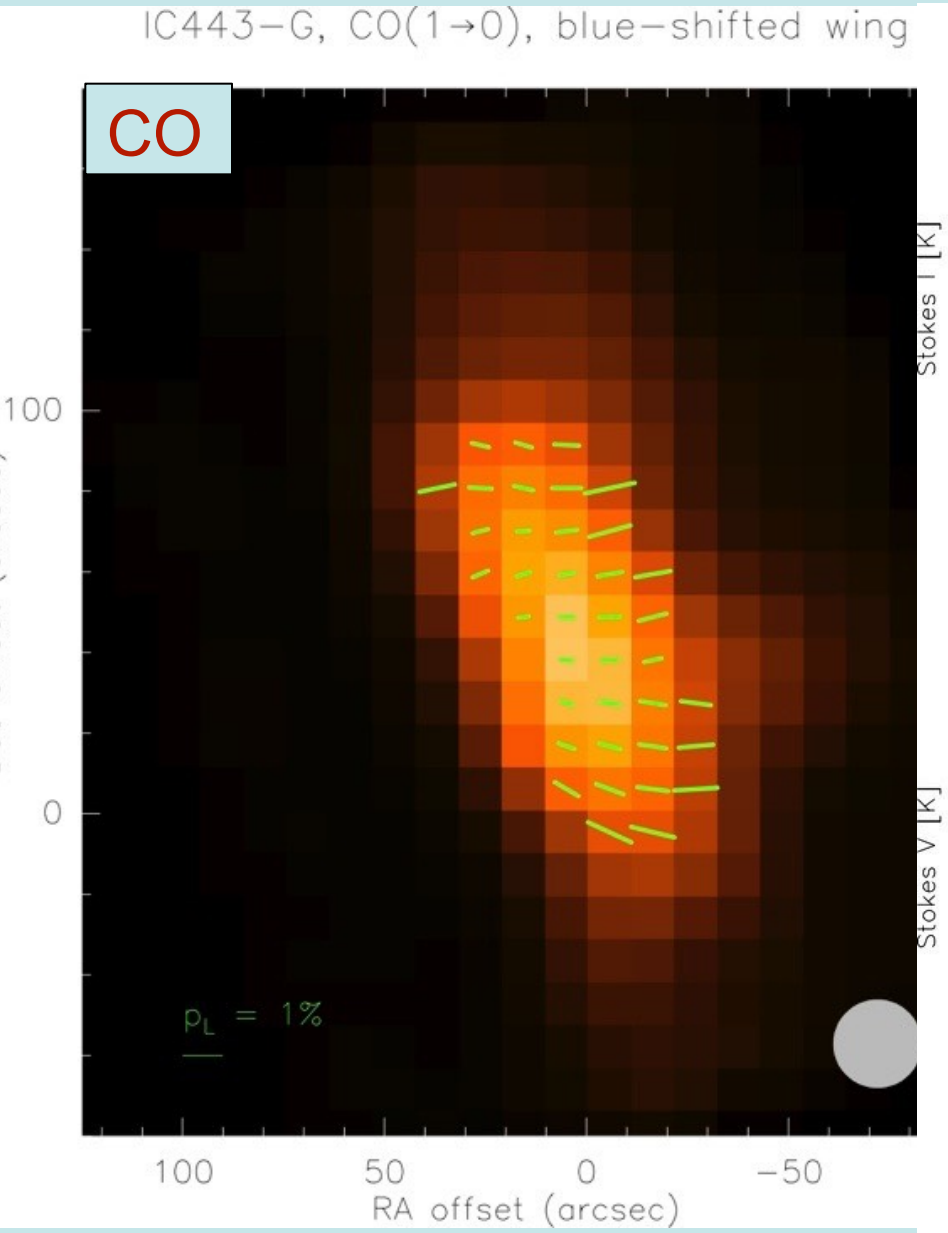


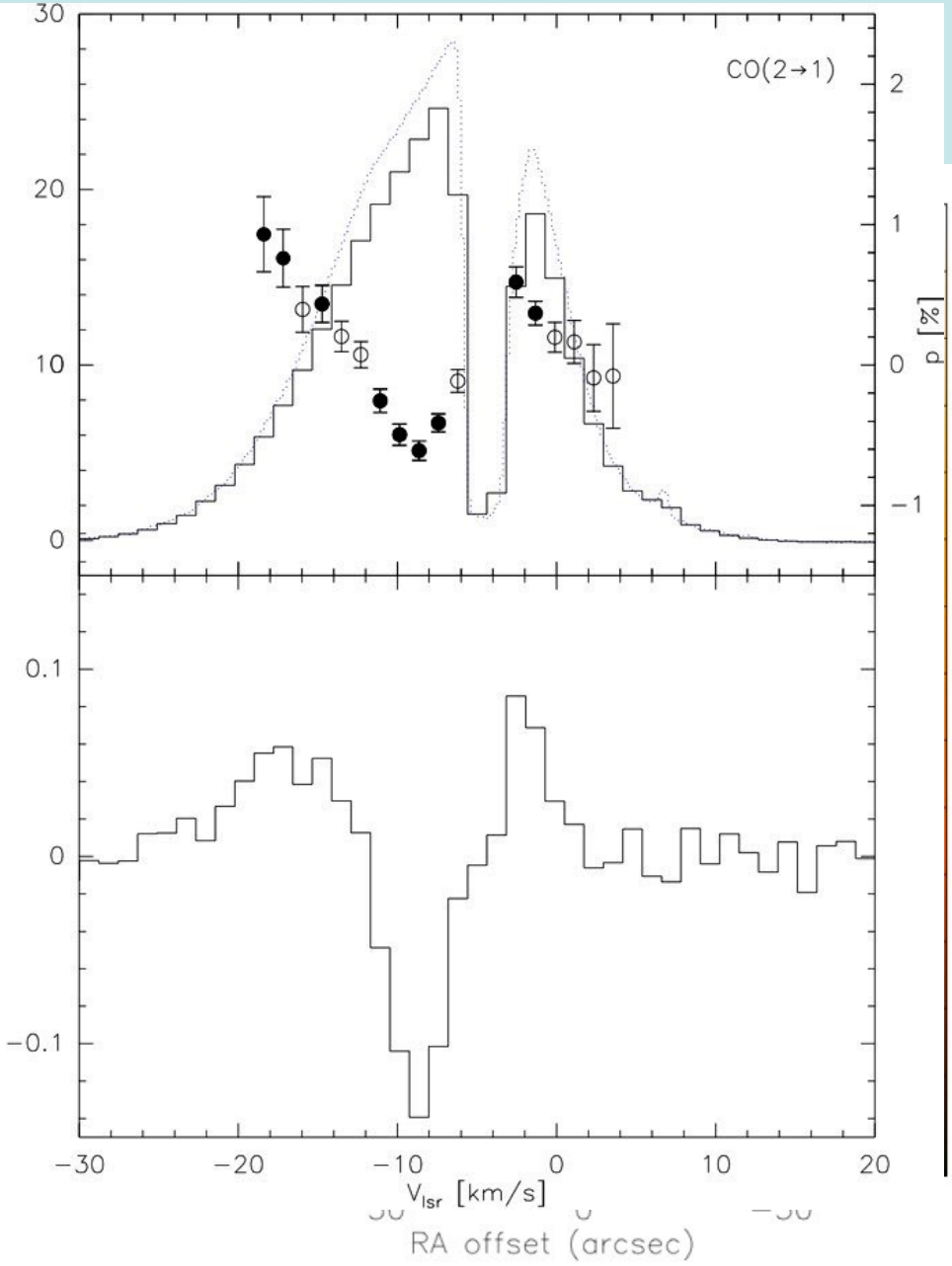
$$\phi \propto B_{\text{pos}}^2$$

$$\tan(2\chi) = \cos(\phi)\tan(2\chi_0)$$

$$U_0 = U\cos(\phi) + V\sin(\phi)$$

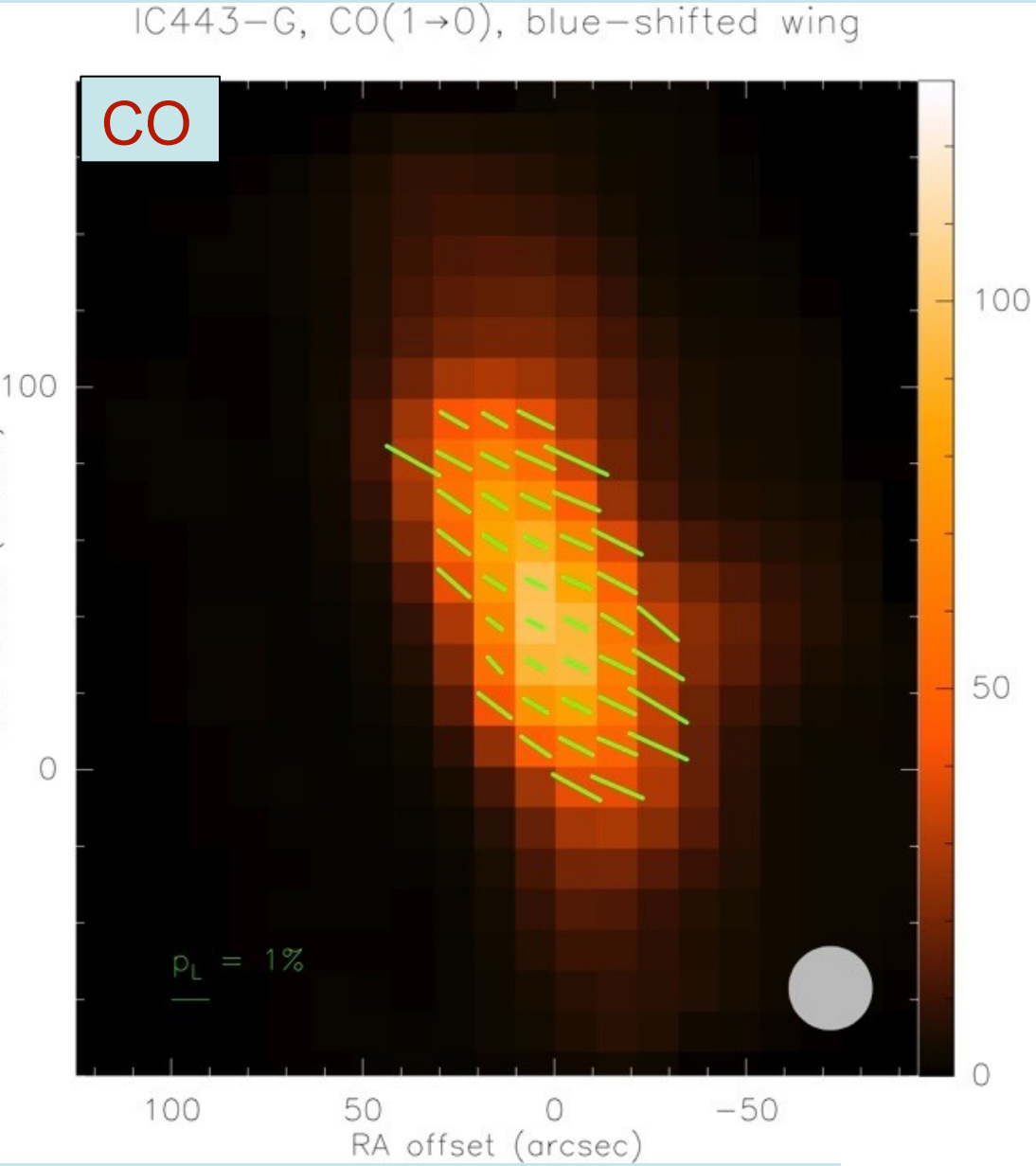
IRAM 30m/APEX - SNR IC 443 (G)

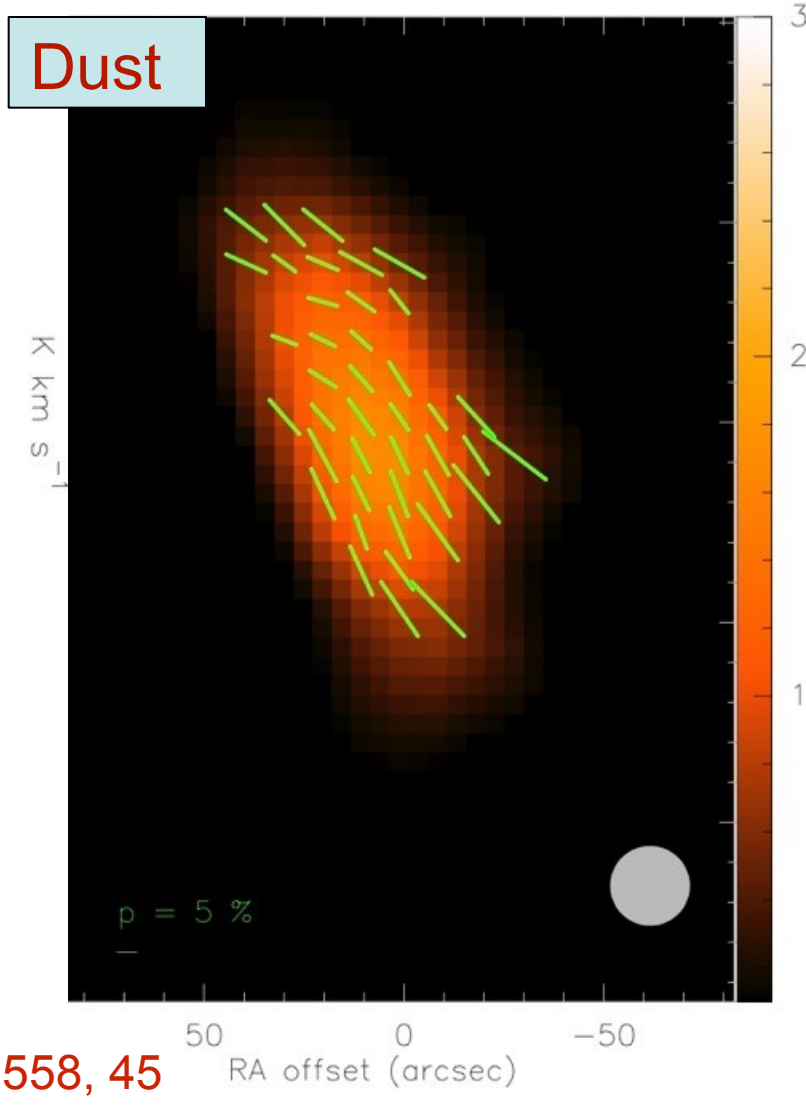




Hezareh+ 20

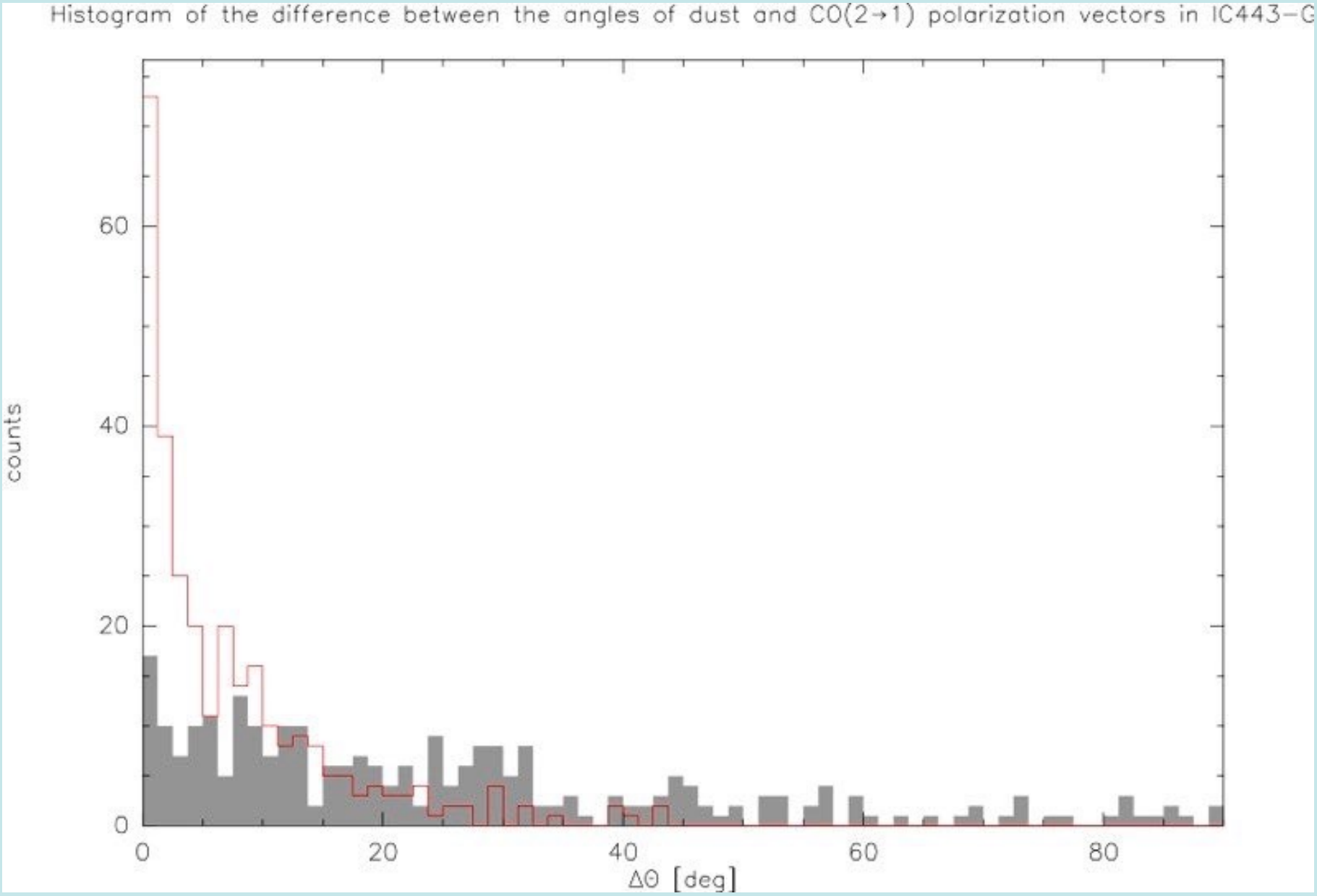
IRAM 30m/APEX - SR IC 443 (G)



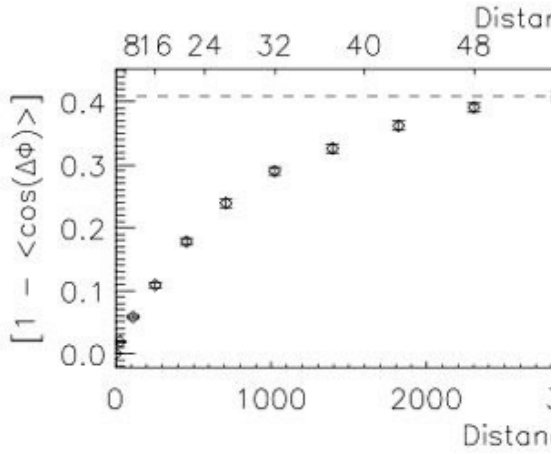


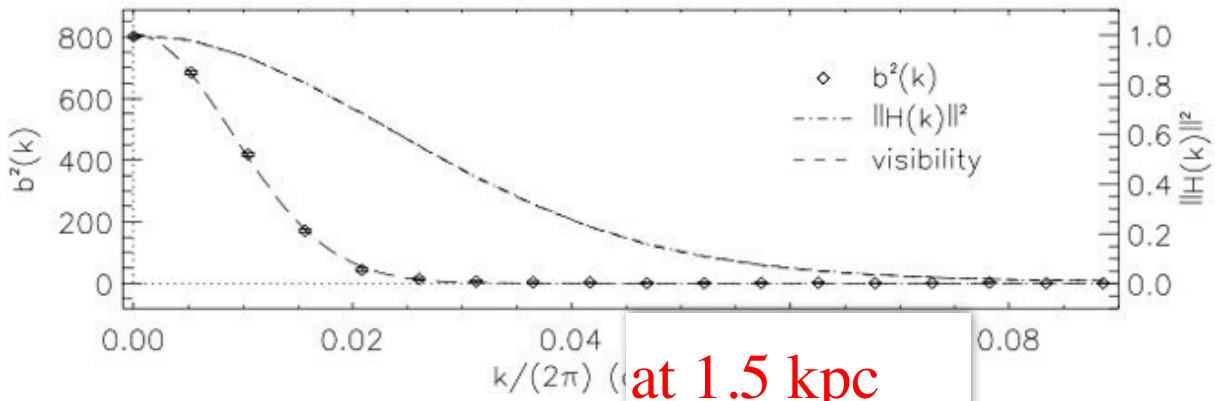
Hezareh+ 2013, A&A, 558, 45

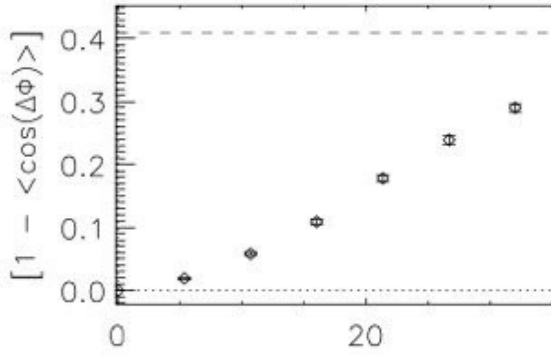
IRAM 30m/APEX - SR IC 443 (G)

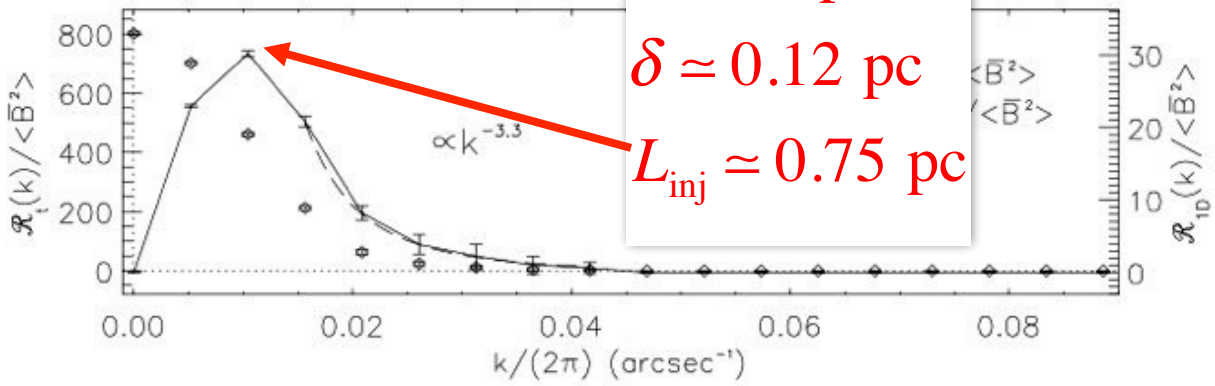


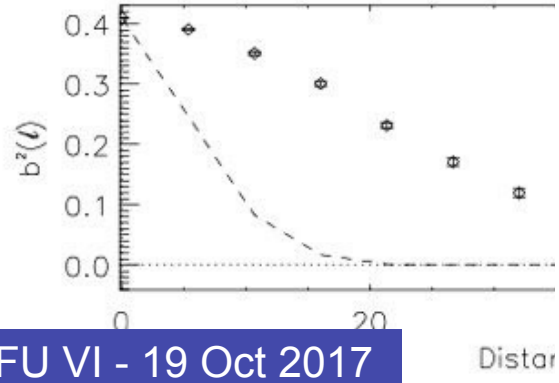
Line Polarization / Dispersion - SNR IC 443

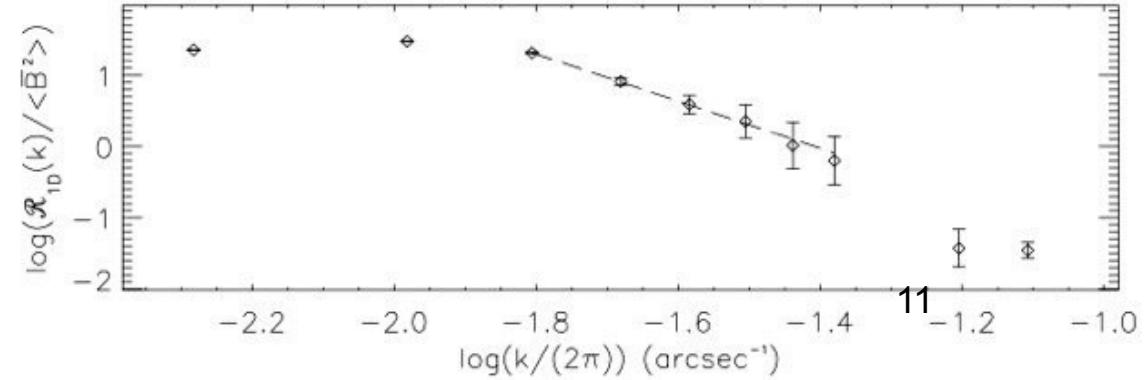










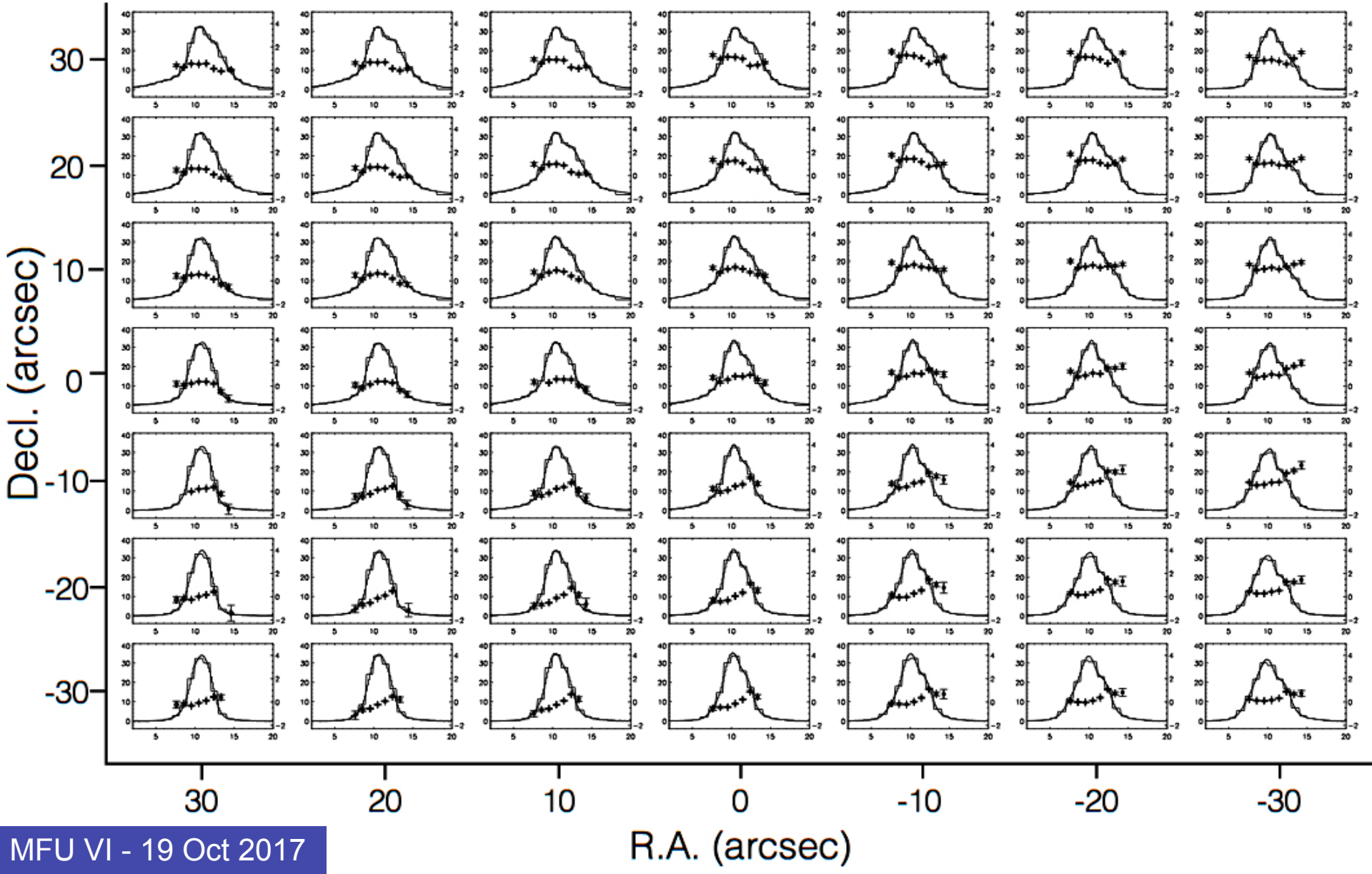


at 1.5 kpc

$\delta \simeq 0.12$ pc

$L_{inj} \simeq 0.75$ pc

Preliminary - OMC-2 FIR 4 (FSPPol/CSO)



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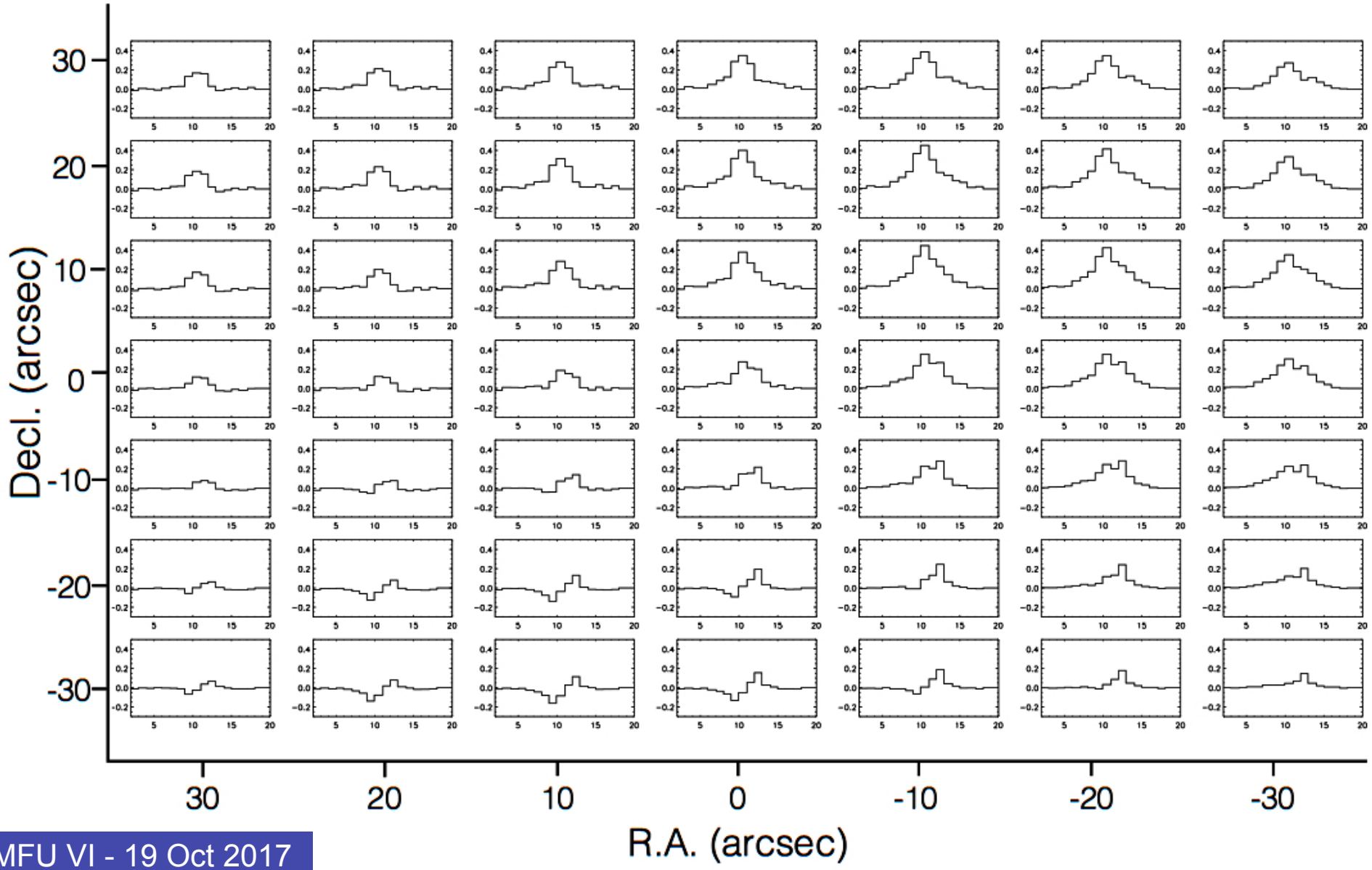
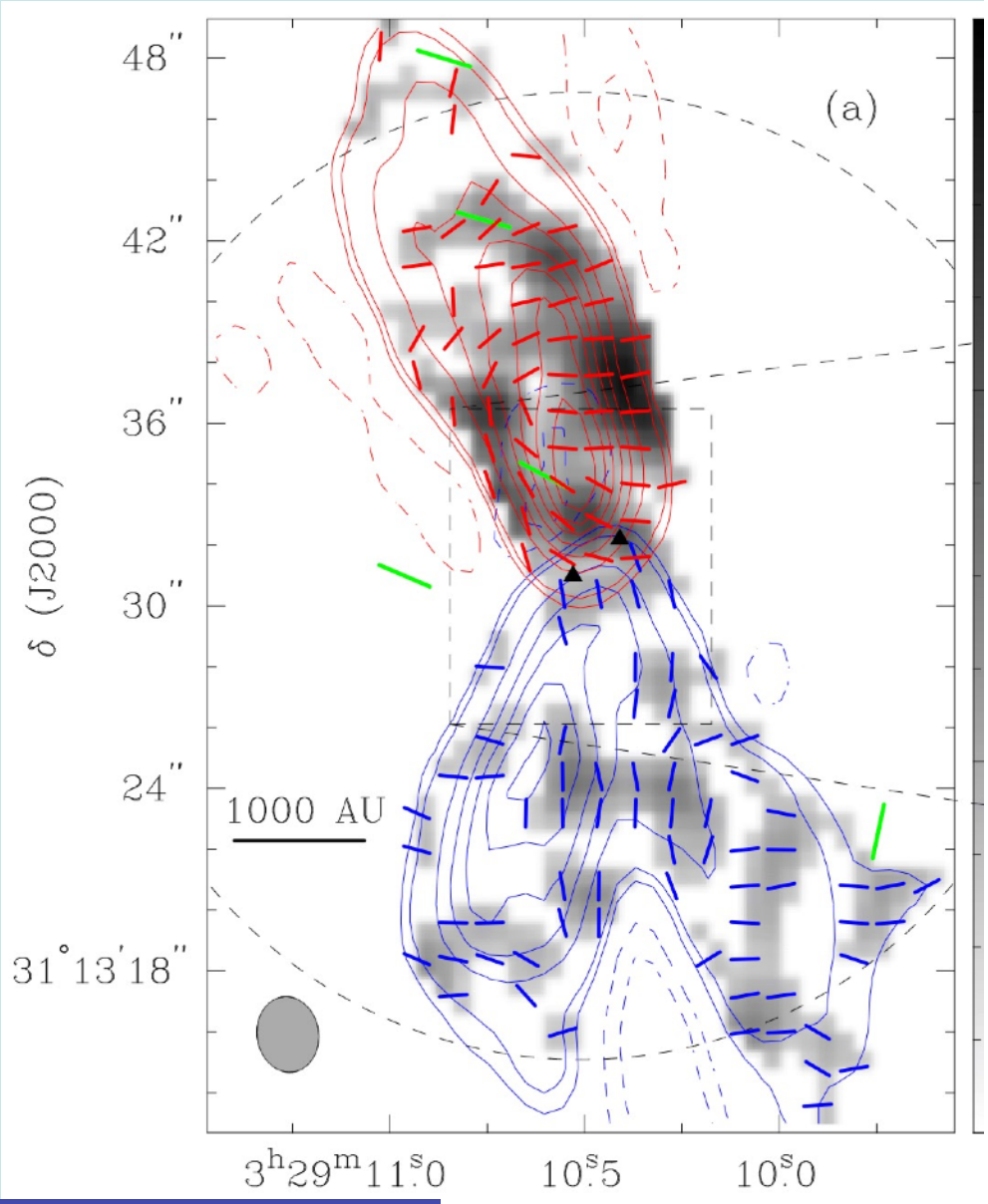
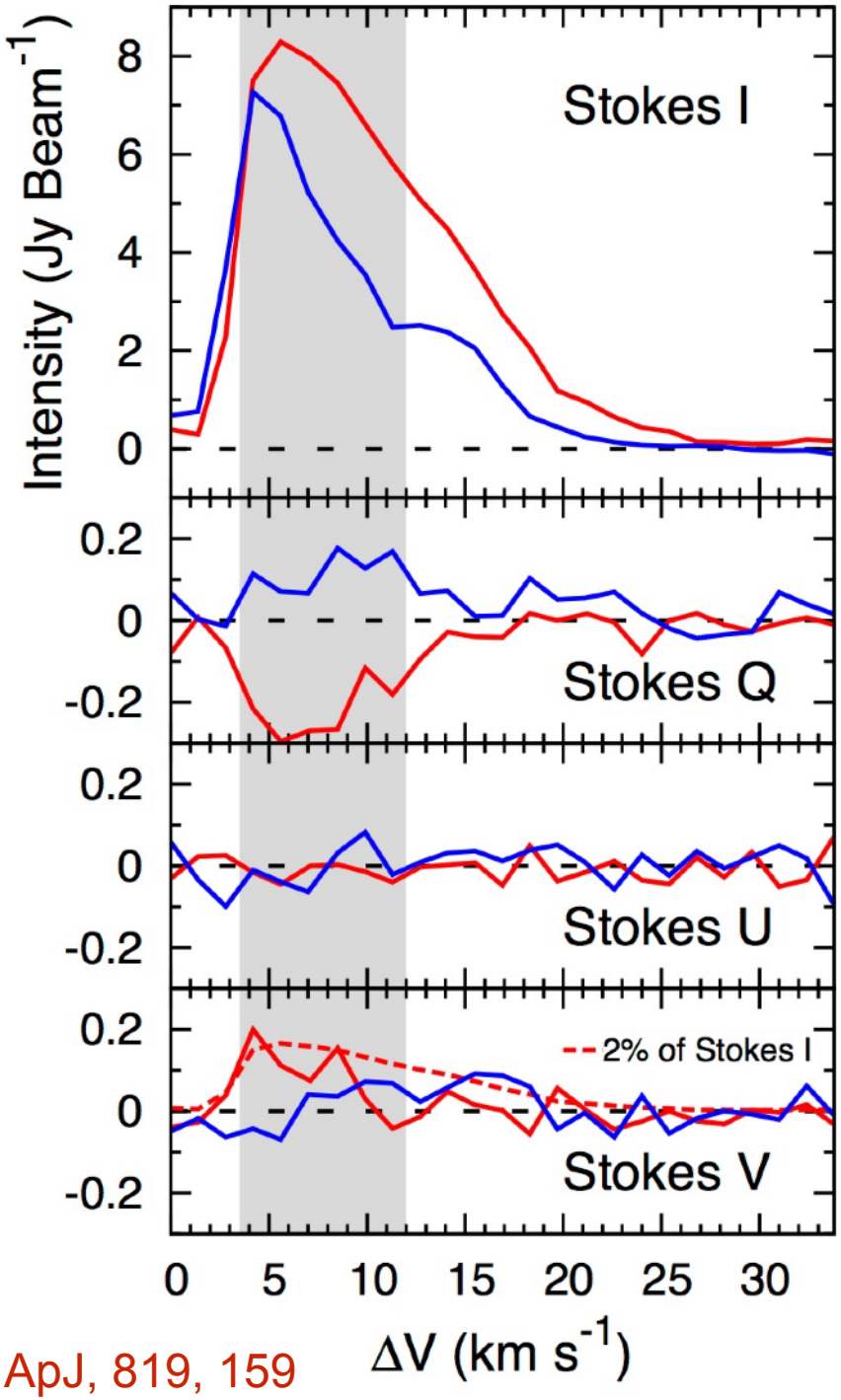


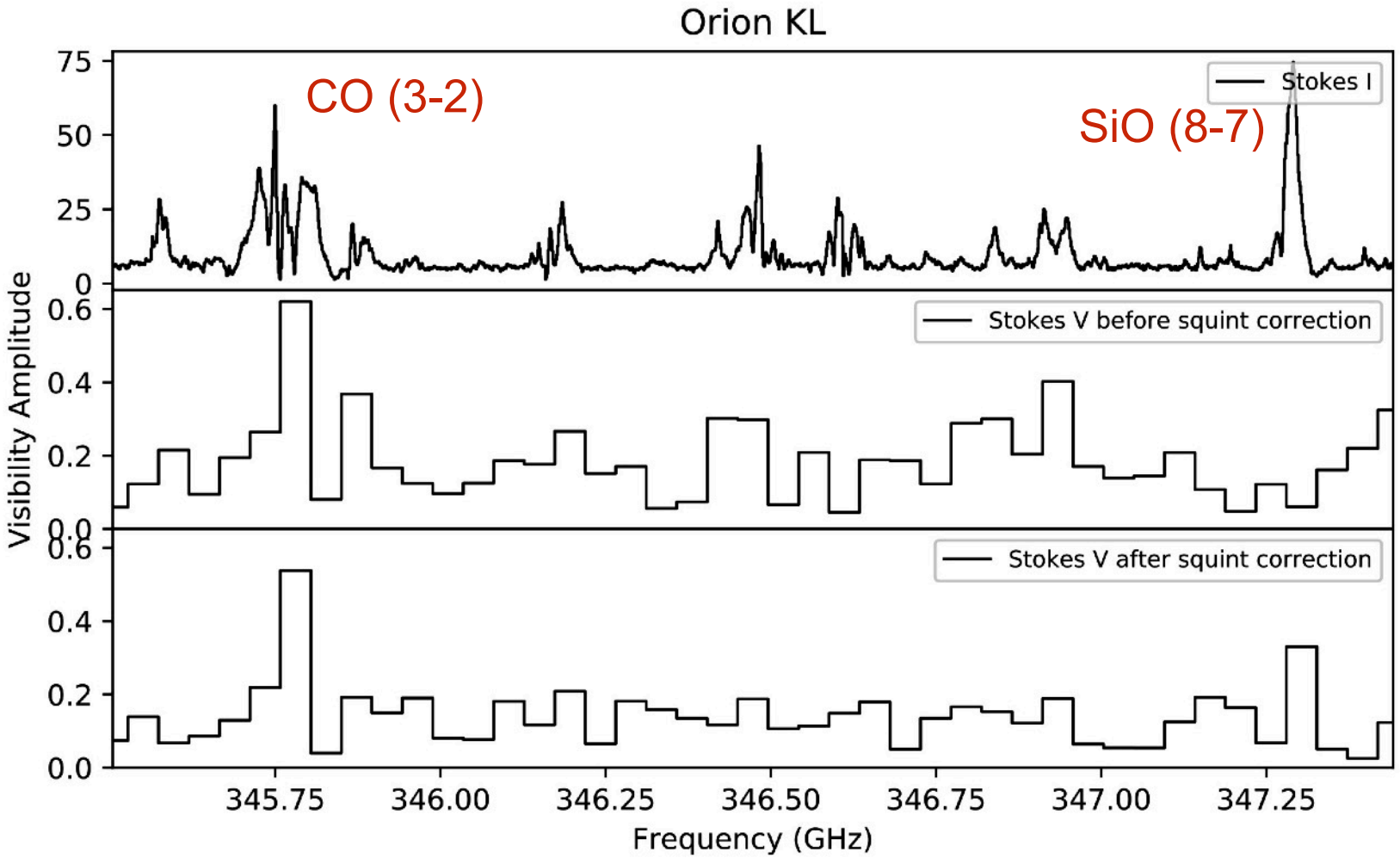
Goldreich-Kylafis (CO





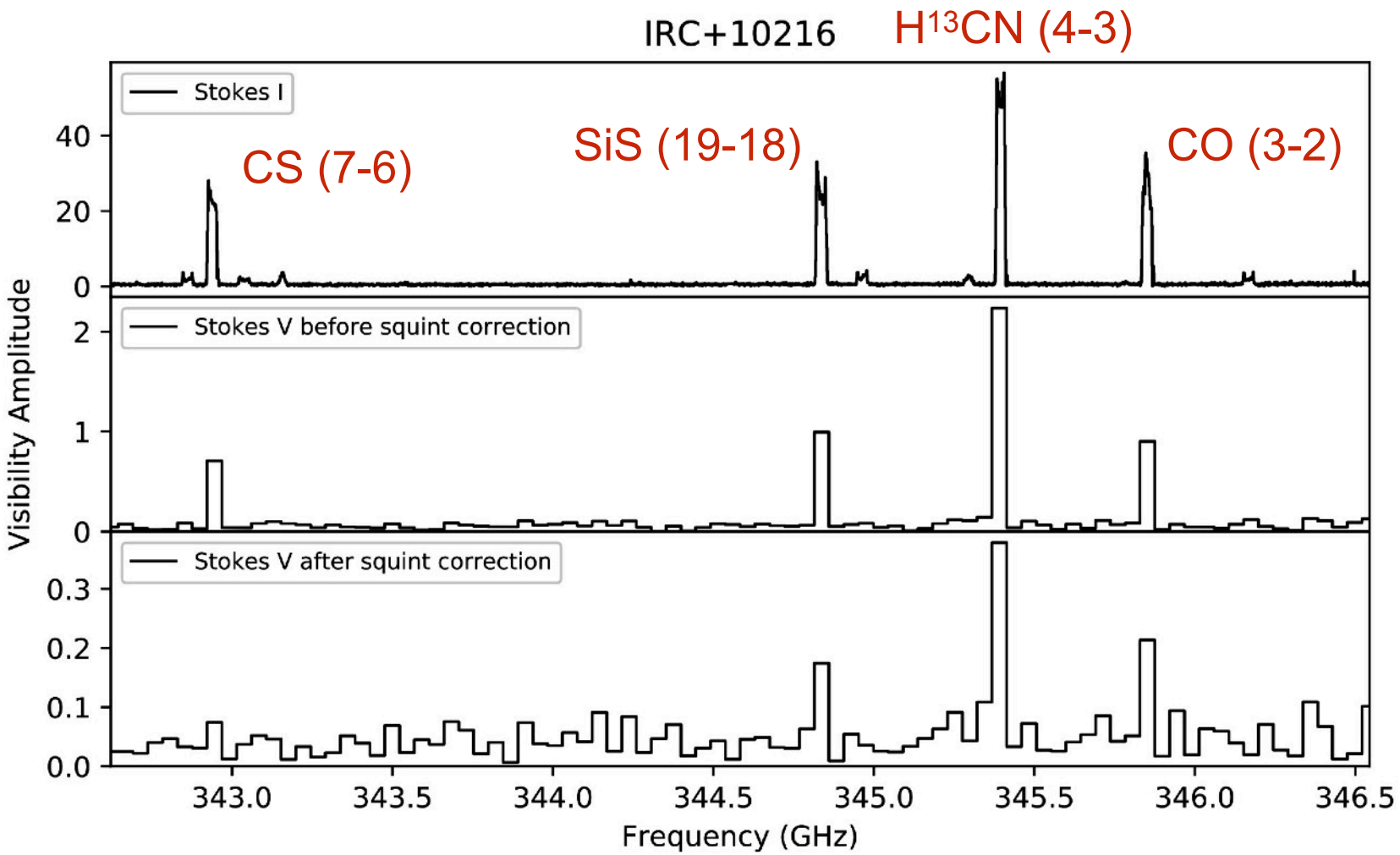
Ching+ 2016, ApJ, 819, 159

Orion KL / SMA (archival)



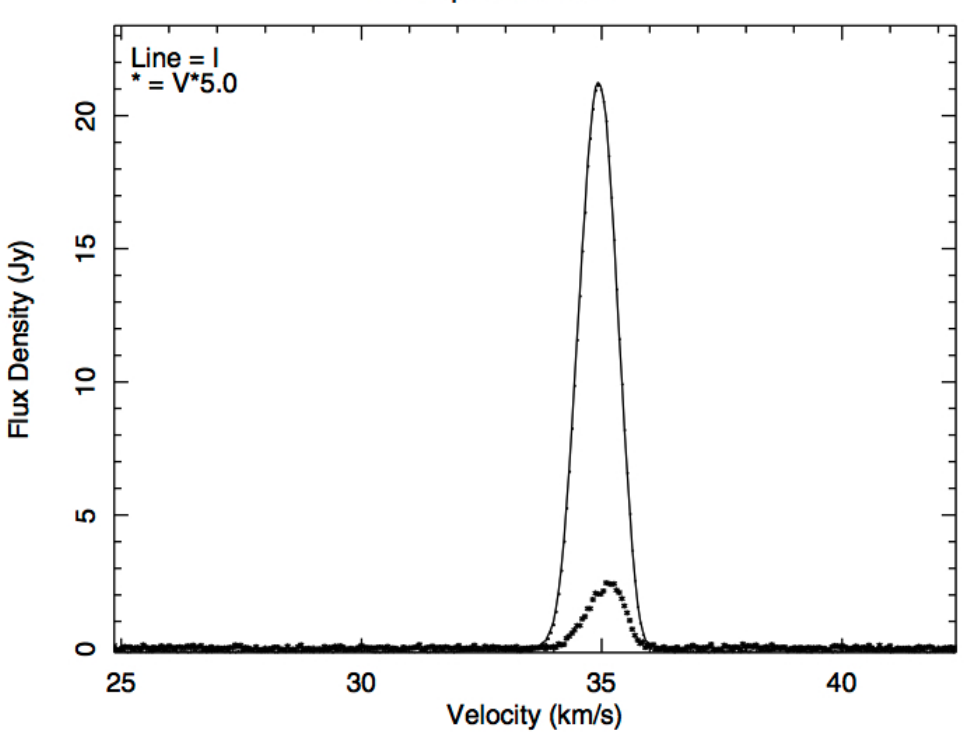
Mohammed Chamma

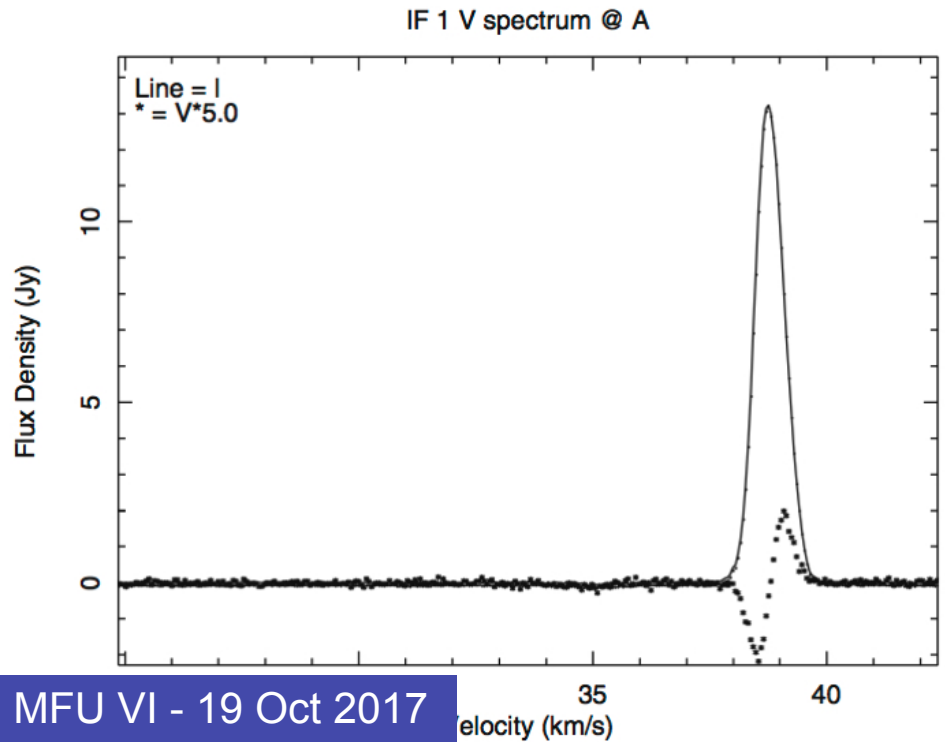
IRAS 10216 / SMA (archive)

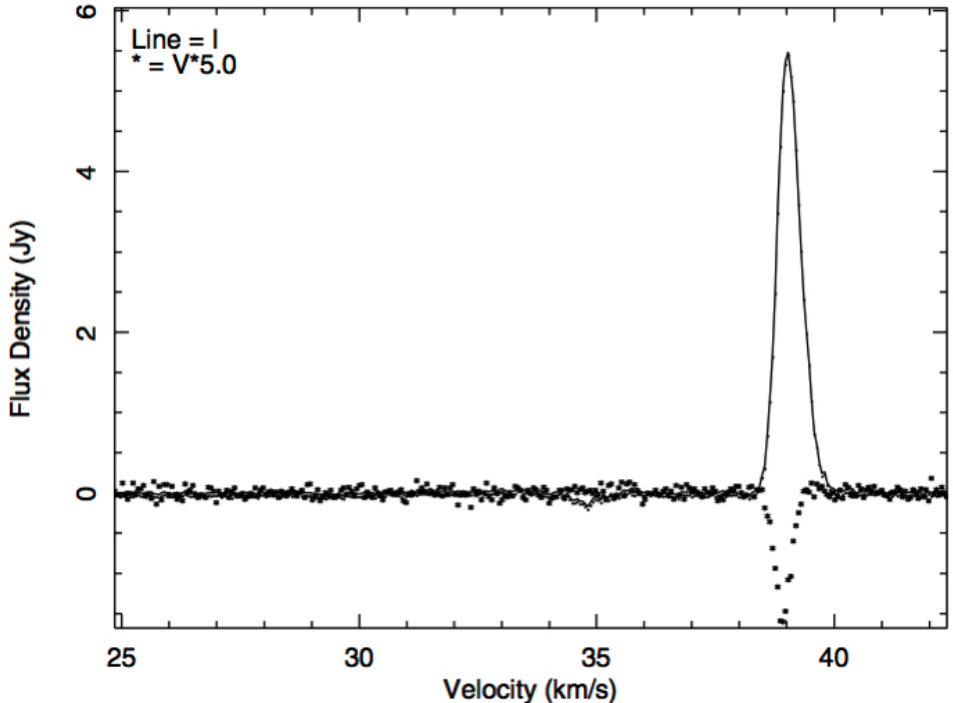


SiO Masers in AGB Star IK Tau

Cotton et al. 2011, ApJ, 736, 96







SiO Masers in AGB Star IK Tau

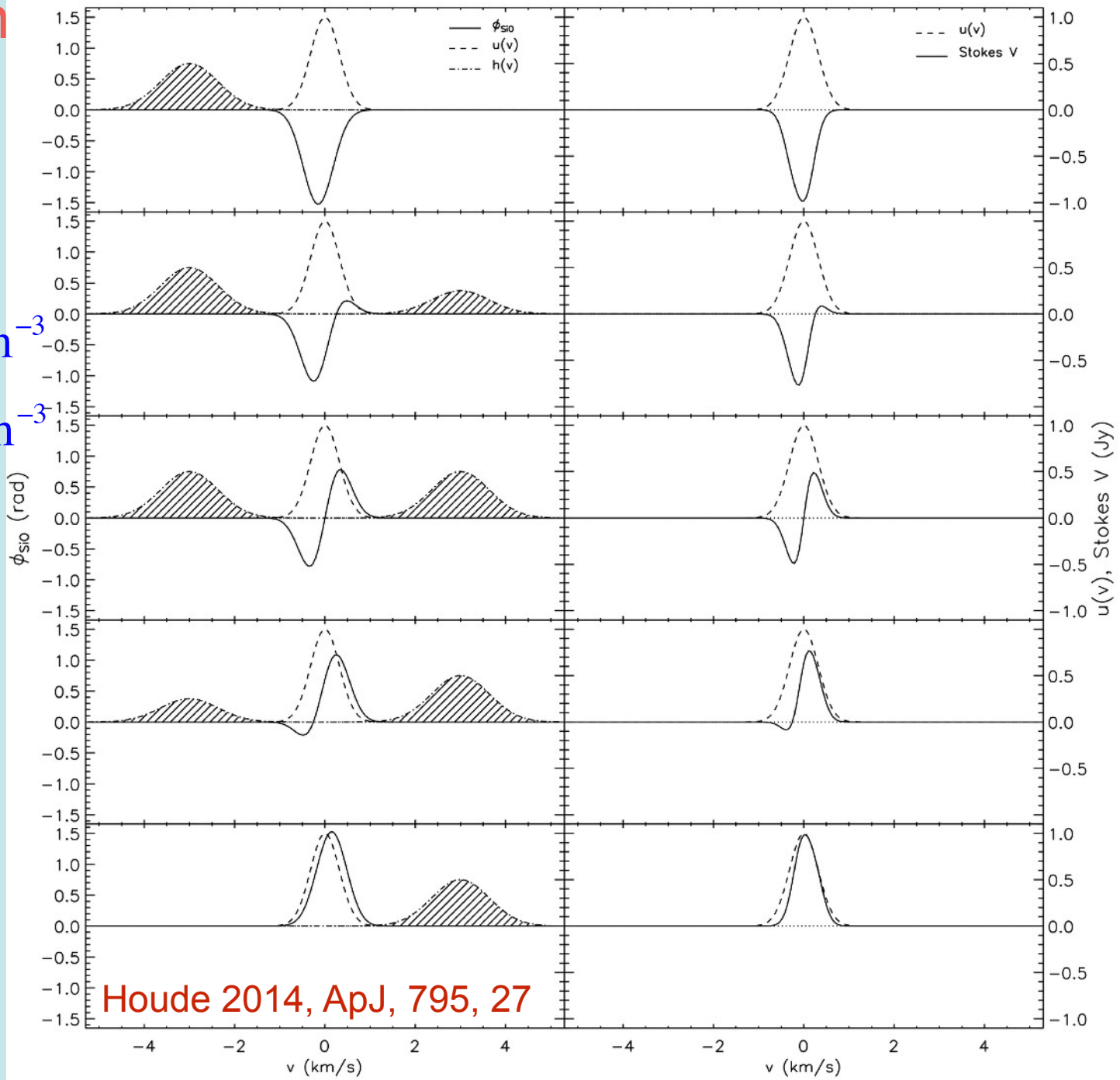
$n_{H_2} = 7.5 \times 10^8 \text{ cm}^{-3}$

$n_{SiO} = 1.2 \times 10^3 \text{ cm}^{-3}$

$T_{ex} = 700 \text{ K}$

$l = 5 \text{ AU}$

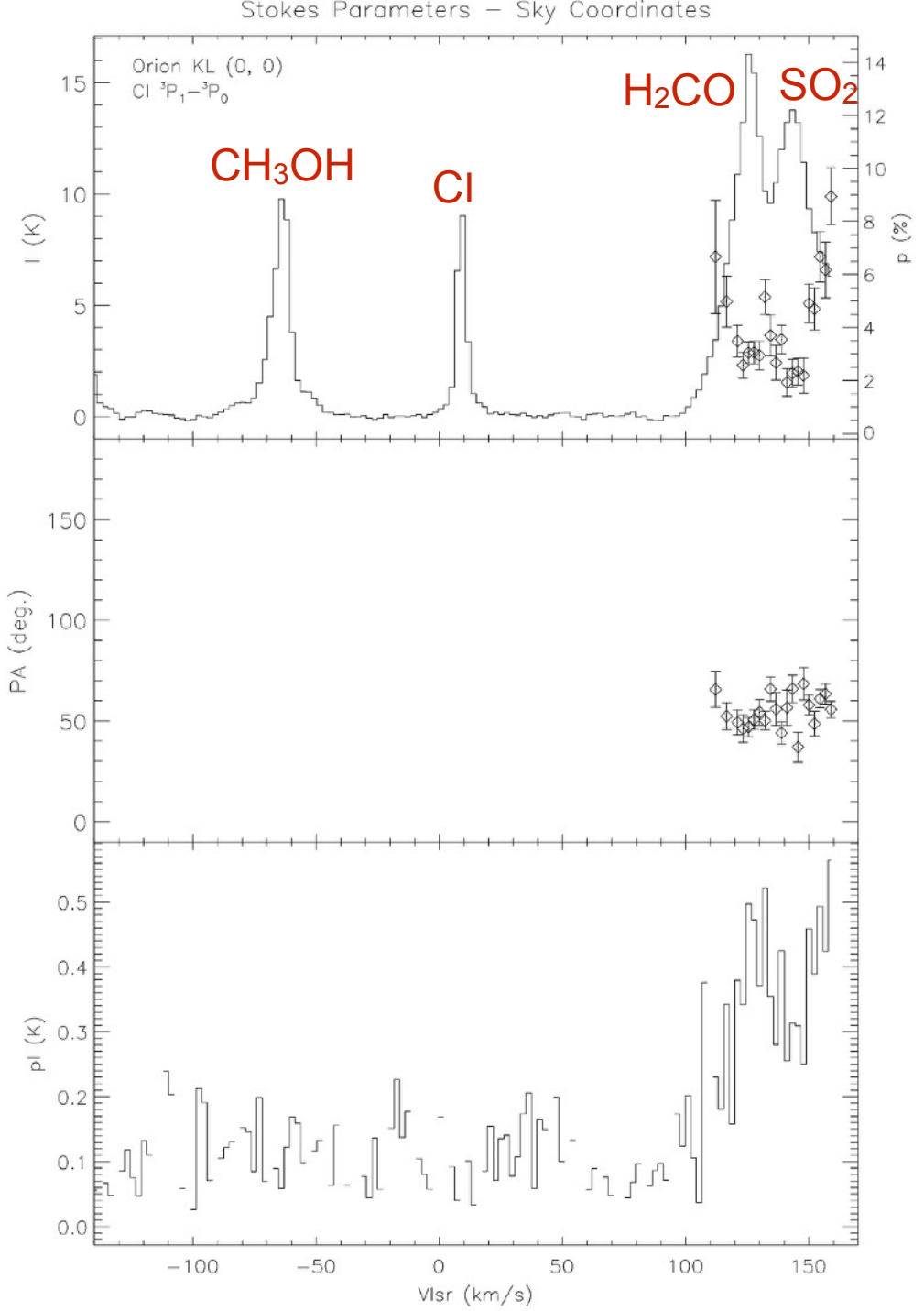
$B = 15 \text{ mG}$



Houde 2014, ApJ, 795, 27

CSO / FSPPol - LP measurements

- CO is not the only species to exhibit polarization
- Different species/lines will trace different density regimes -> tomography
- Much better suited for the DCF technique



Summary

- Detection of non-Zeeman circular polarization in CO and other spectral lines.
  - Appears to be widespread.
- We can account for the levels of CP through anisotropic resonant scattering (Orion KL, SNR IC 443(G), and IK Tau).
- Analysis from linear polarization of spectral lines (e.g., for Davis-Chandrasekhar-Fermi analysis) CANNOT be performed without considering CP.
- Explains long-standing problem of CP in SiO masers (IK Tau).

$\Rightarrow$ Effect proportional to $B^2_{\rm pos}$ $\Leftarrow$

Merci !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