Non-Zeeman Circular Polarization of Molecular Spectral Lines in the Interstellar Medium

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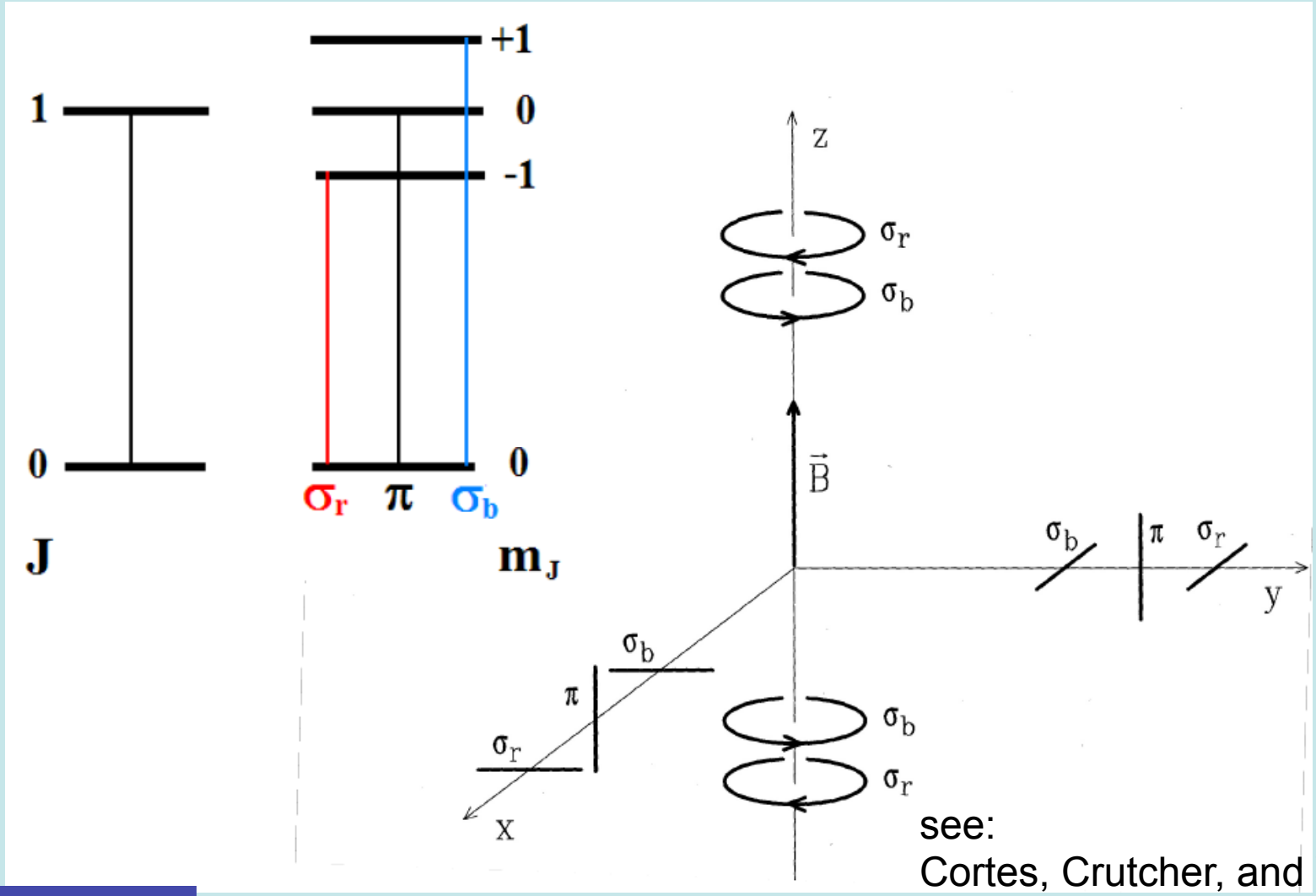
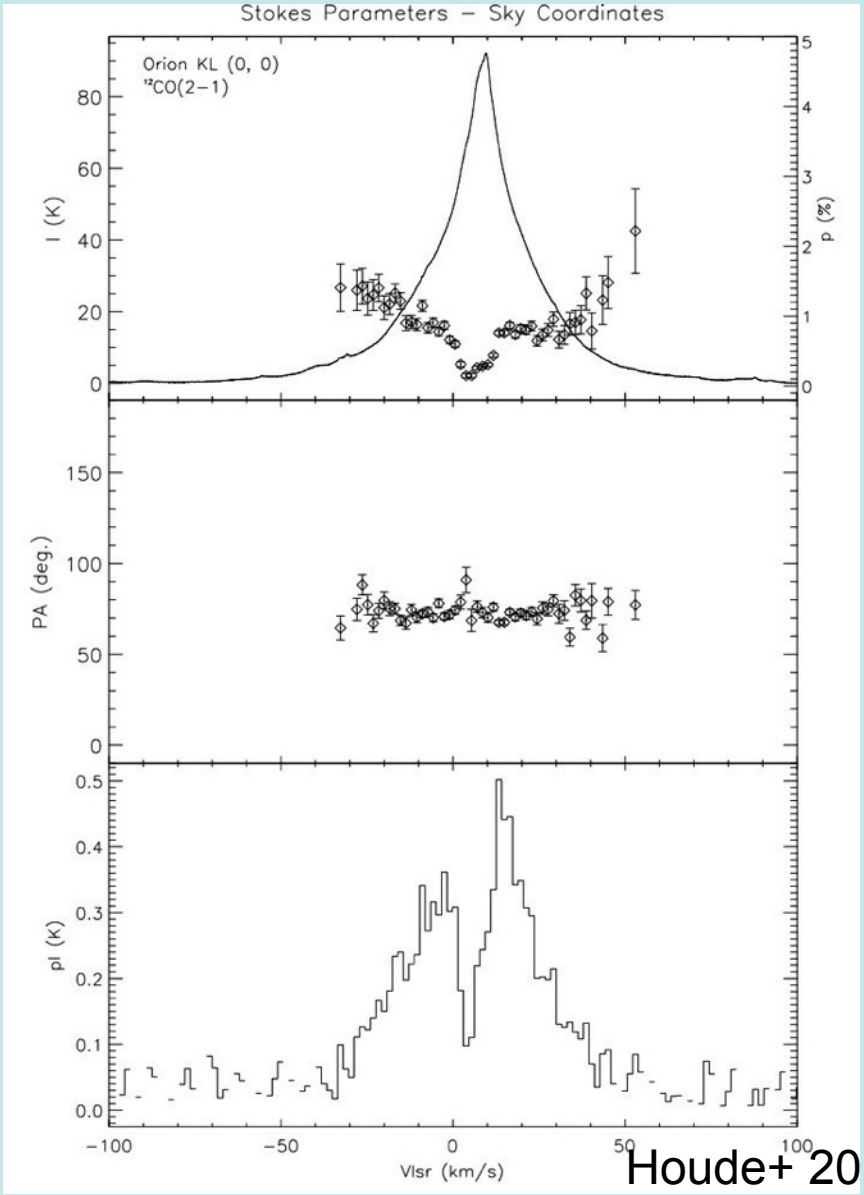
Linear Polarization of Molecular Lines - Goldreich-Kylafis Effect



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

B Fields and Molecular Lines - Goldreich-Kylafis Effect



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

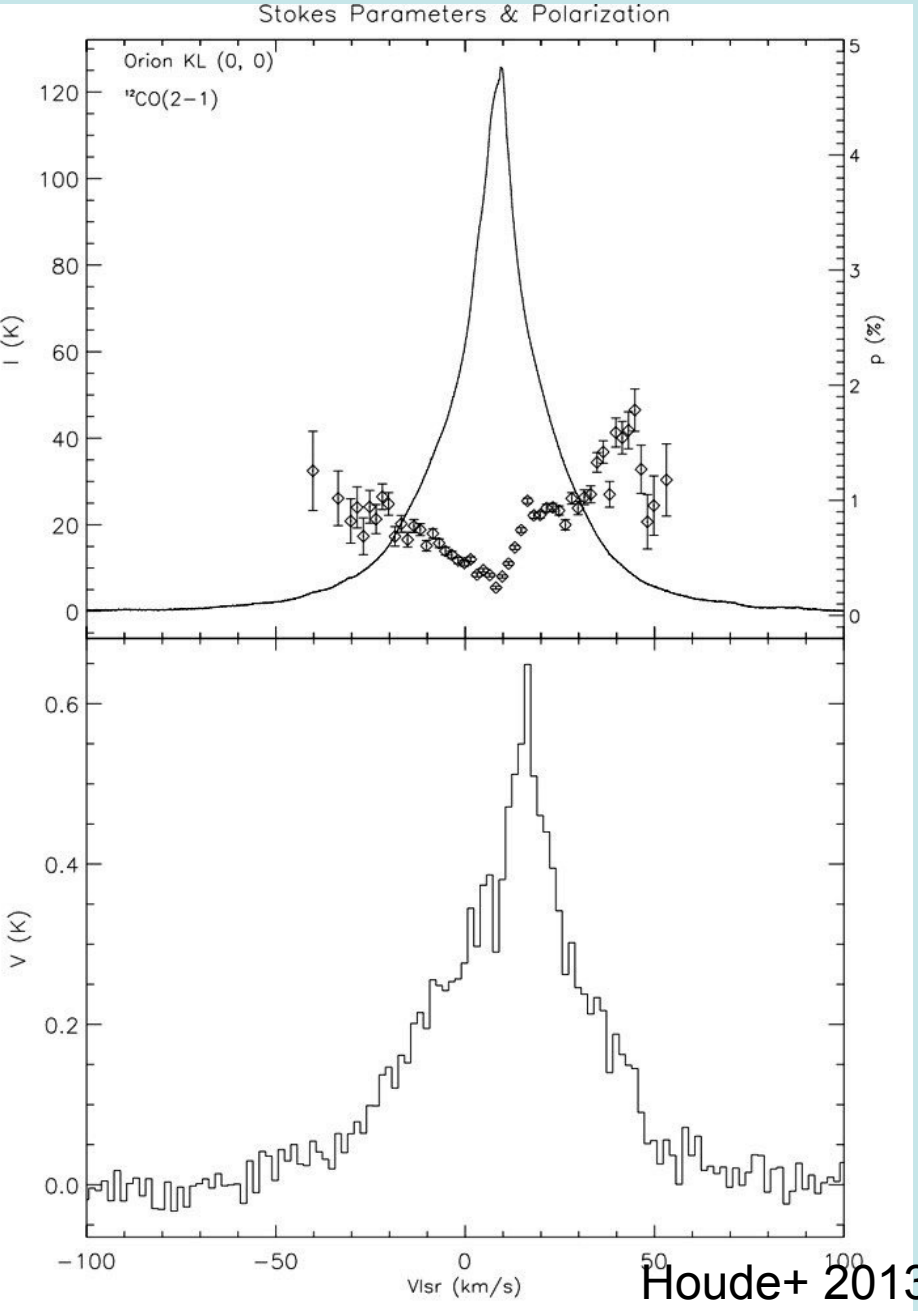
Houde+ 2013, ApJ, 764, 24

Goldreich-Kylafis Effect
A Generalization to Circular Polarization?

- Is it possible to have imbalance between the population of the sub-levels leading to the two σ-lines?
- Short answer → no in the ISM...
- Then, is there another way of generating circular polarization in molecular lines?
  - The answer → very difficult ...

- ⇒ We should not expect to find CP in spectral lines from negligibly Zeeman-sensitive molecular species ⇐

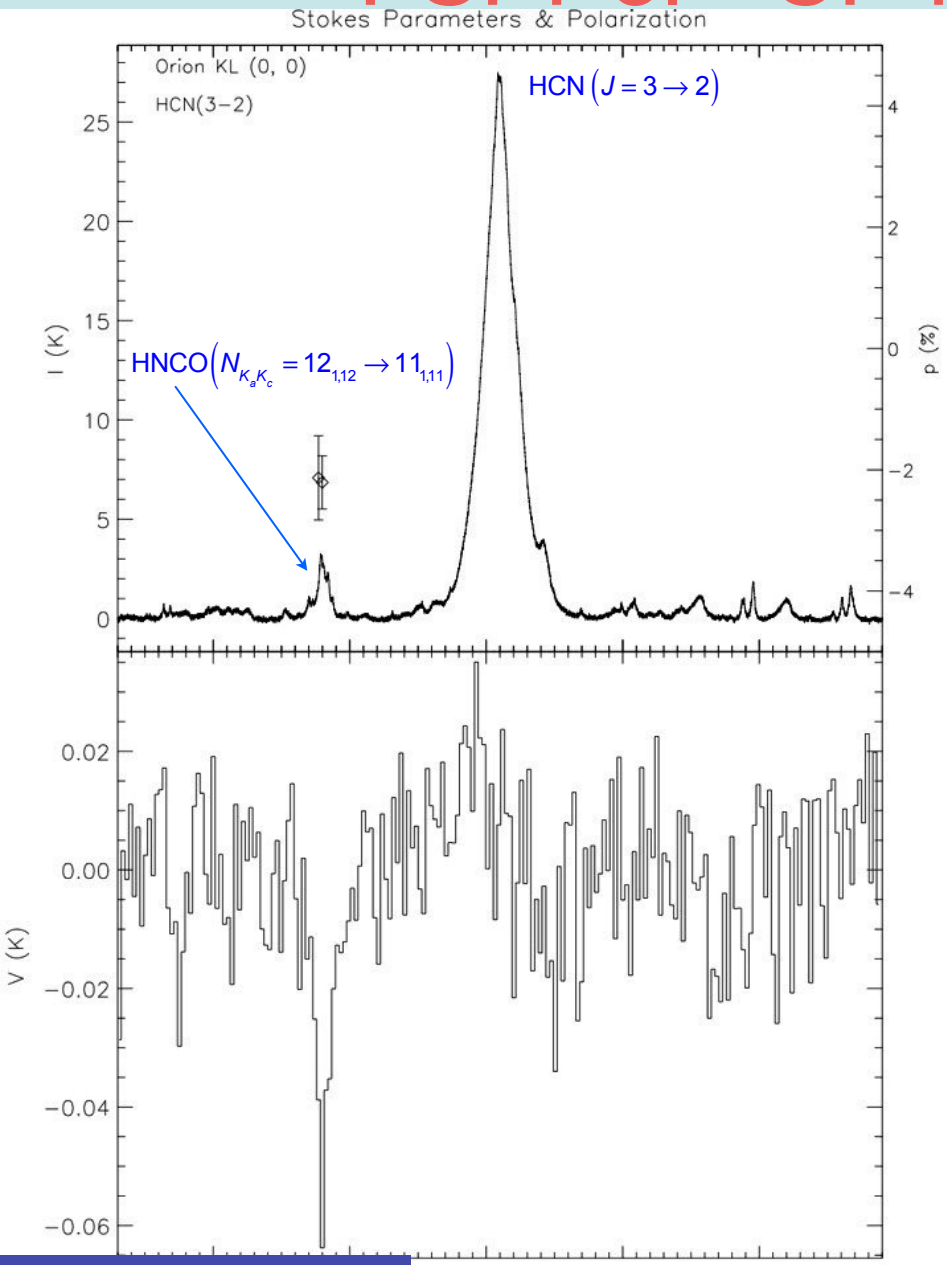
CSO / FSPPol - CP Measurements

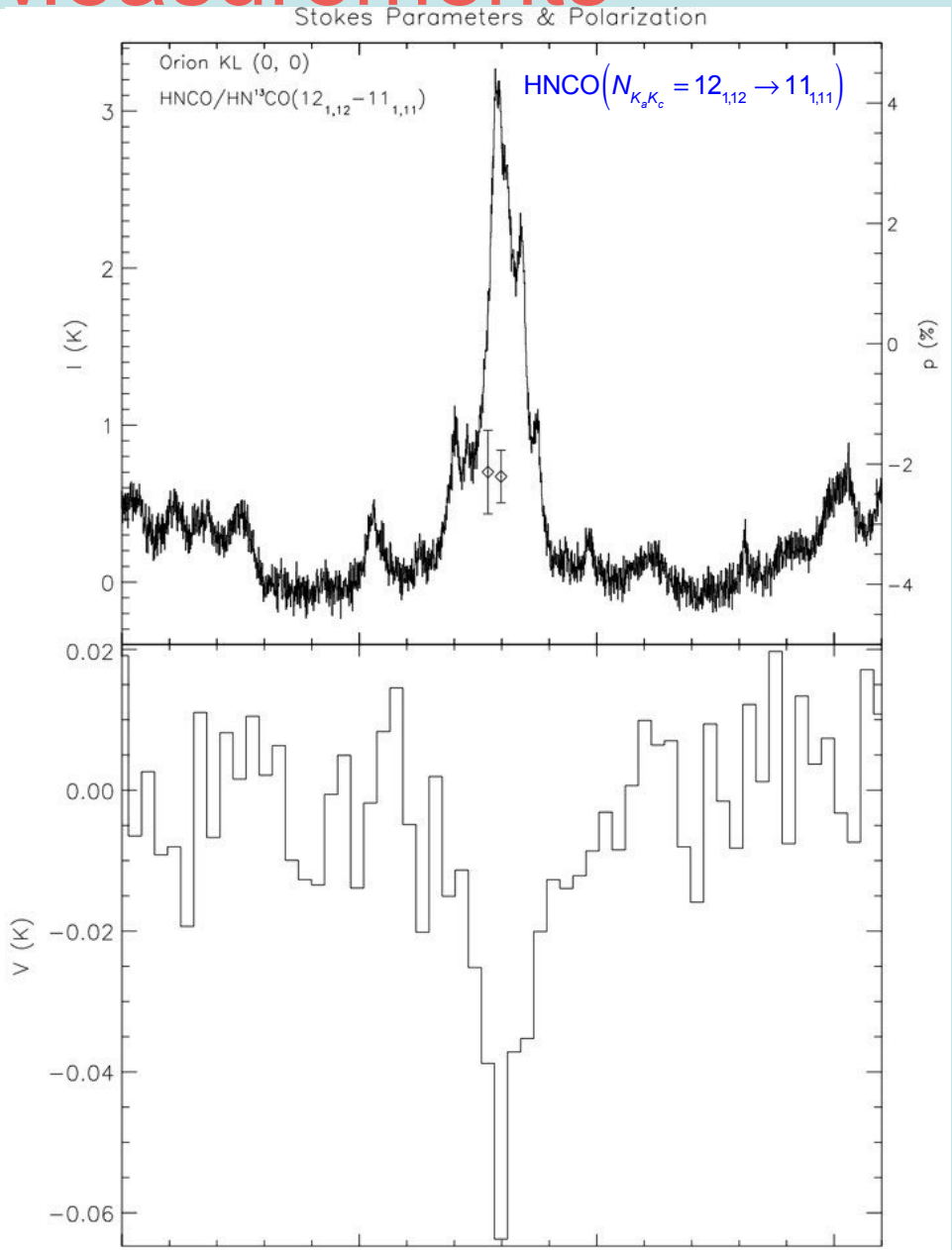


- Circular polarization measurements in Orion KL of the $^{12}C^{16}O\ (J = 2 \rightarrow 1)$ rotational line at 230.5 GHz with FSPPol
- Zeeman splitting ~ 0.2 mHz/μG
  - ~4 orders of magnitude less than CN
- Is it an instrumental artifact?
  - Measured twice: Nov. 2011 and Feb. 2012
  - and...

Houde+ 2013, ApJ, 764, 24

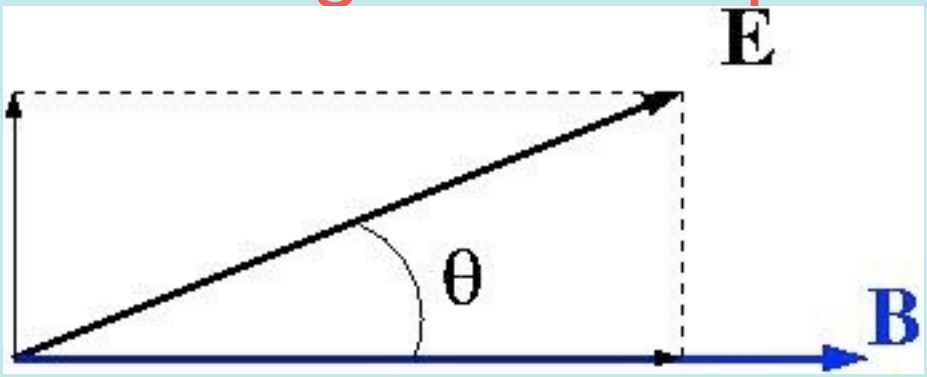
FSPPol - CP Measurements





Houde+ 2013, ApJ, 764, 24

(Faraday) Conversion of LP to CP - through Anisotropic Resonant Scattering



Radiation State of LP at angle θ

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

$$|\psi_0\rangle = \underbrace{|a\rangle}_{\text{lower state}}\ \underbrace{|\|\rangle}_{\text{radiation}} \xrightarrow{\text{absorption}} \underbrace{|b\rangle}_{\text{excited state}}\ \underbrace{|\|-1\rangle}_{\text{minus photon}} \xrightarrow{\text{emission}} \underbrace{|a\rangle}_{\text{lower state}}\ \underbrace{|\|_1\rangle}_{\text{radiation}}$$

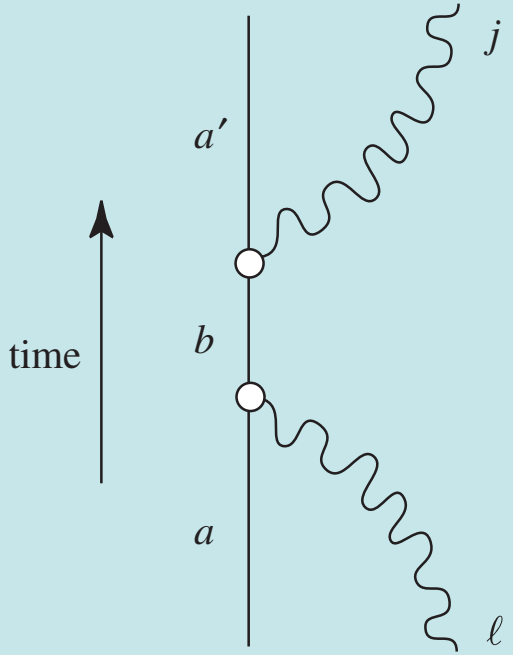
For one scattering the final state becomes

$$|\|_1\rangle \simeq (1 + i\phi_{\|})|\|\rangle \simeq e^{i\phi_{\|}}|\|\rangle$$

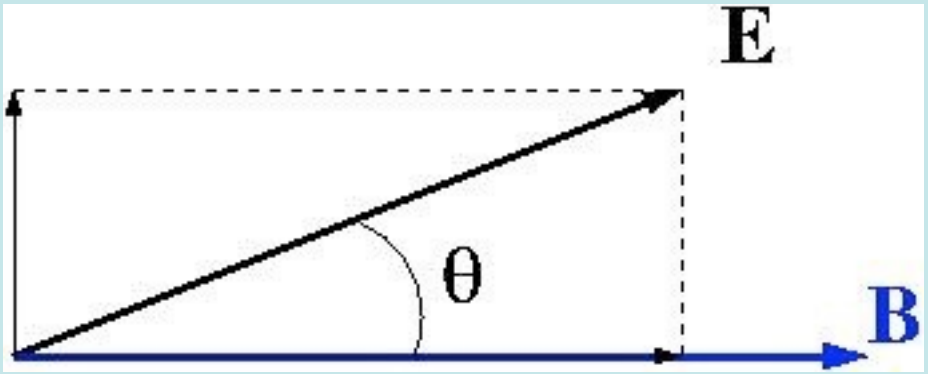
$$|\perp_1\rangle = |\perp\rangle$$

After N scatterings

$$|\|_N\rangle \simeq e^{iN\phi_{\|}}|\|\rangle, \quad |\perp_N\rangle = |\perp\rangle$$



Anisotropic Resonant Scattering



Radiation State of LP at angle θ

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

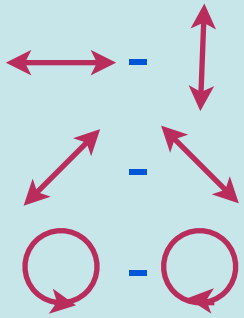
with $\alpha = \cos(\theta), \beta = \sin(\theta)$

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

$$Q = Q_0$$

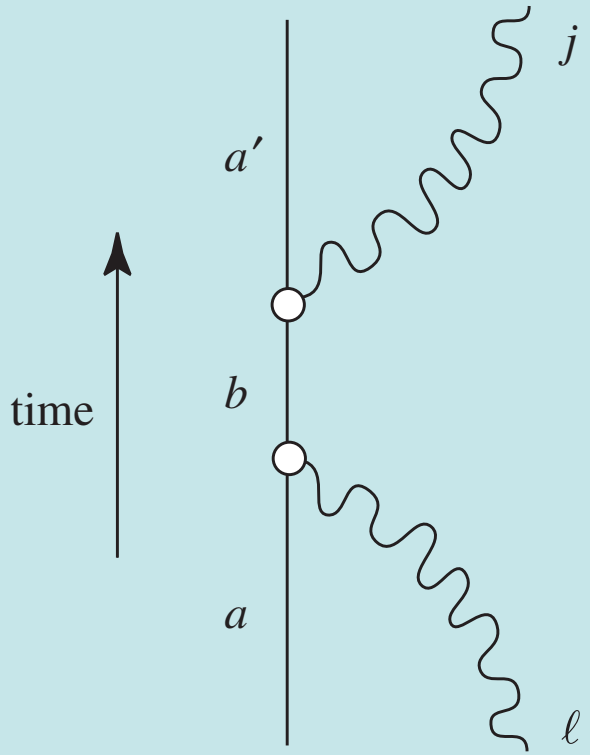
$$U = U_0 \cos(\phi)$$

$$V = V_0 \sin(\phi)$$

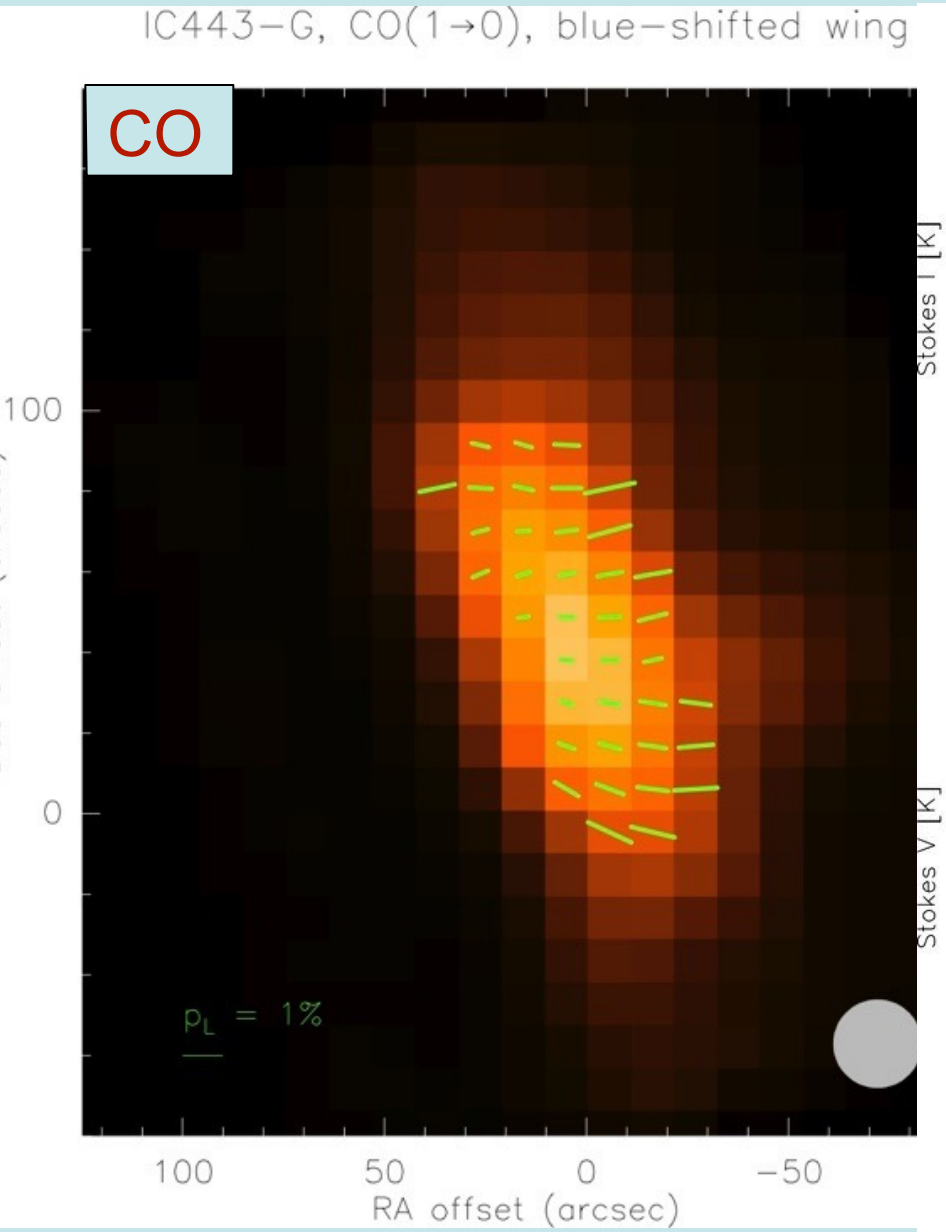


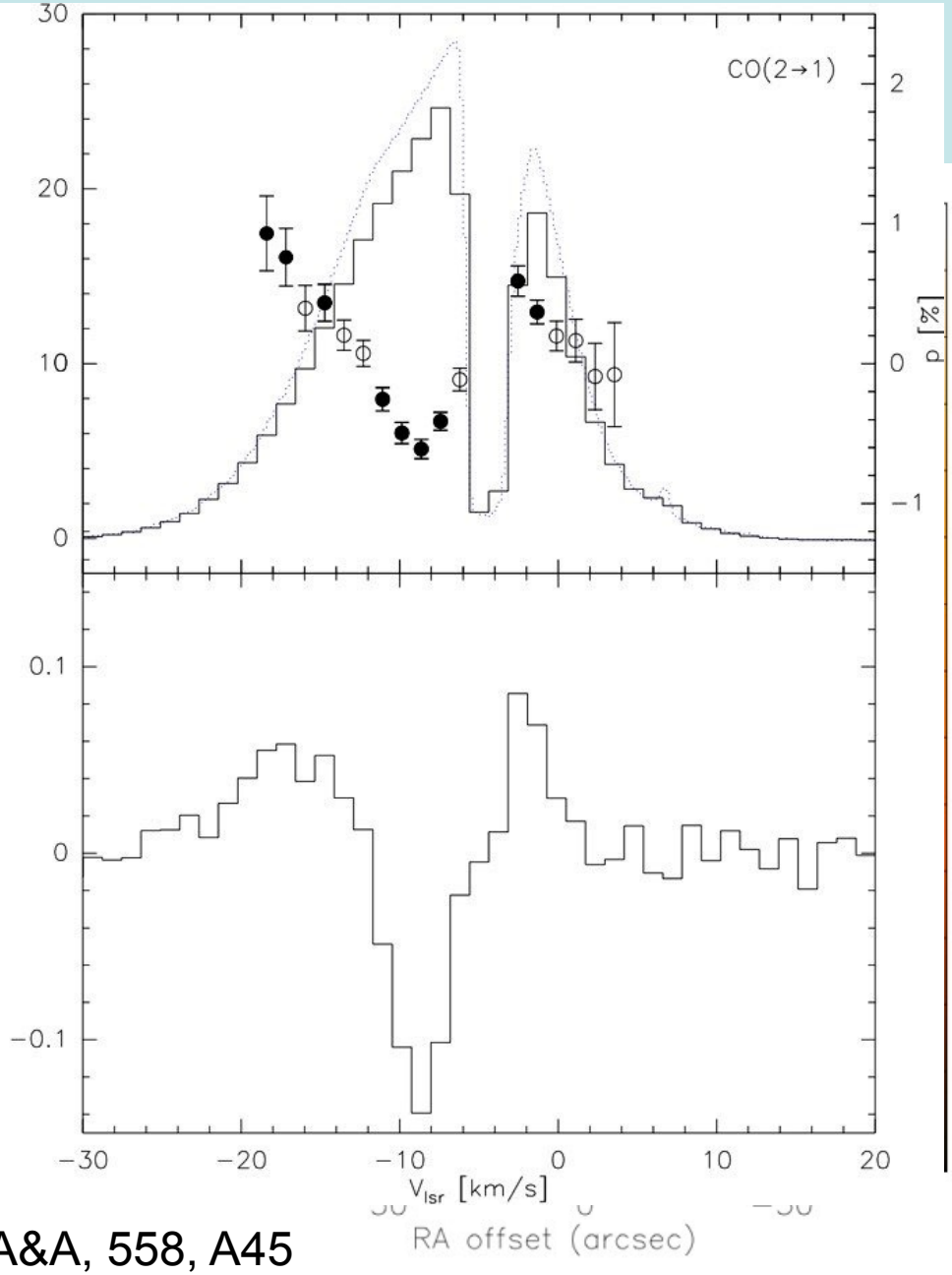
$$\tan(2\chi) = \cos(\phi)\tan(2\theta)$$

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



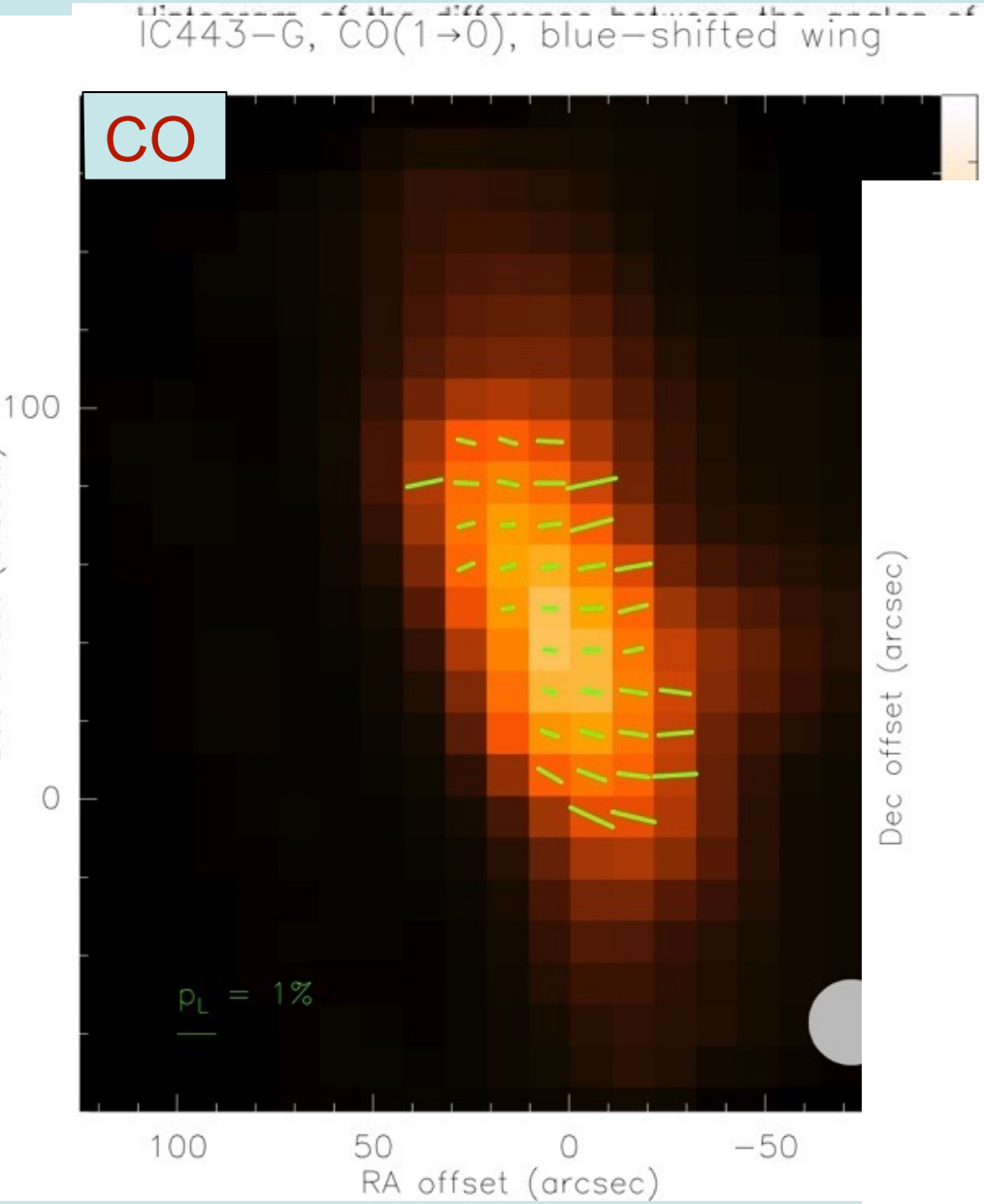
IRAM 30m - SNR IC 443 (G)

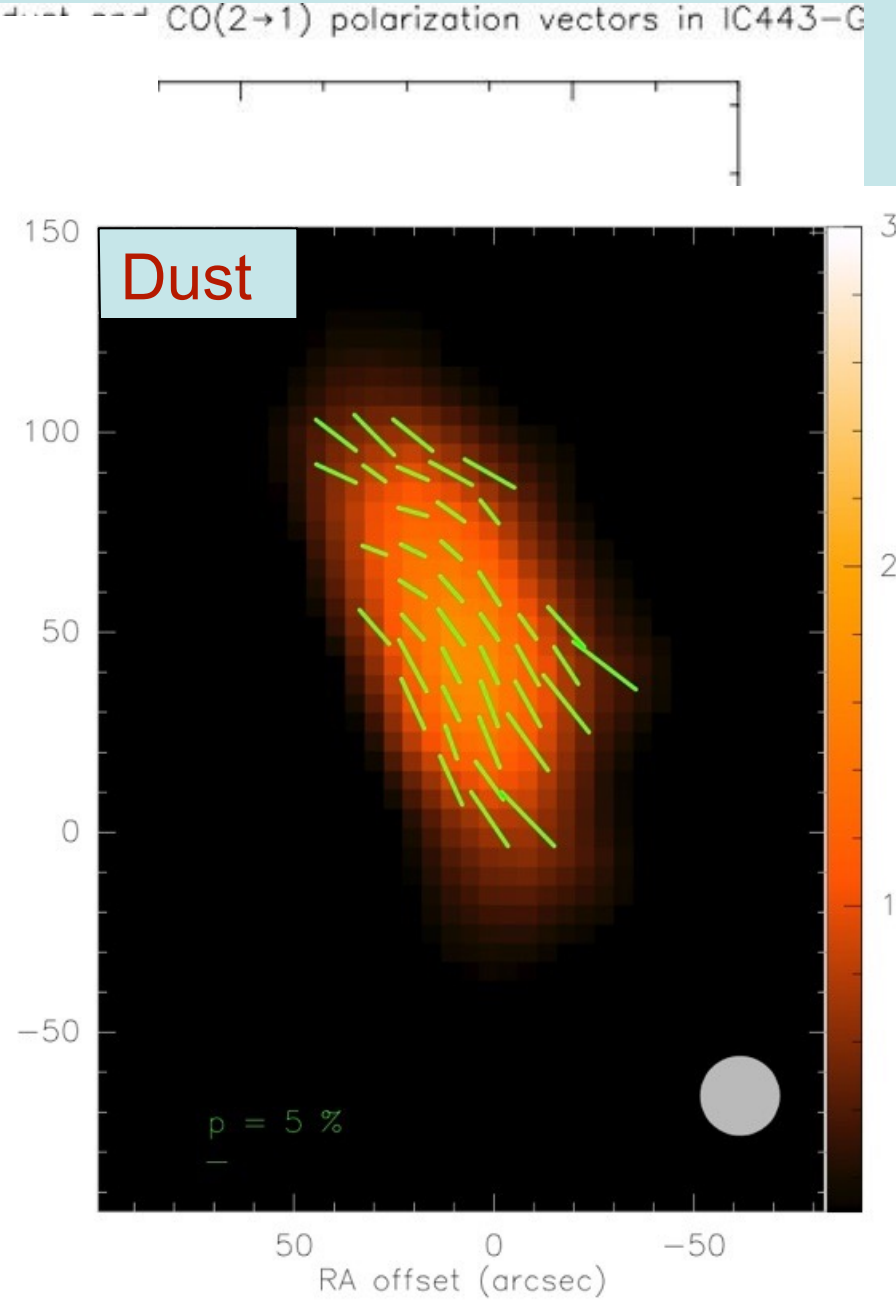




Hezareh+ 2013, A&A, 558, A45

IRAM 30m - SR IC 443 (G)





Hezareh + 20

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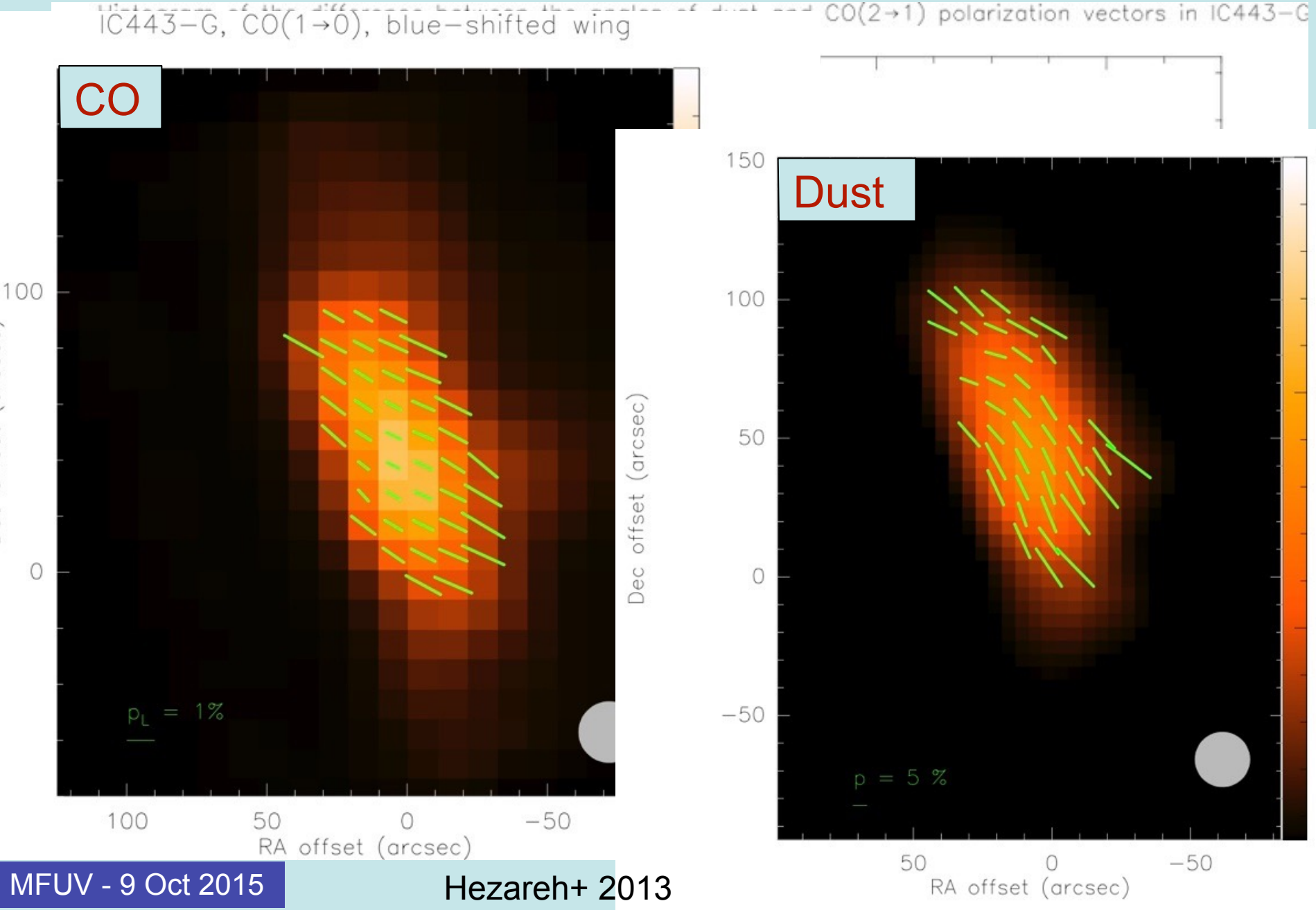

Hezareh+ 2013

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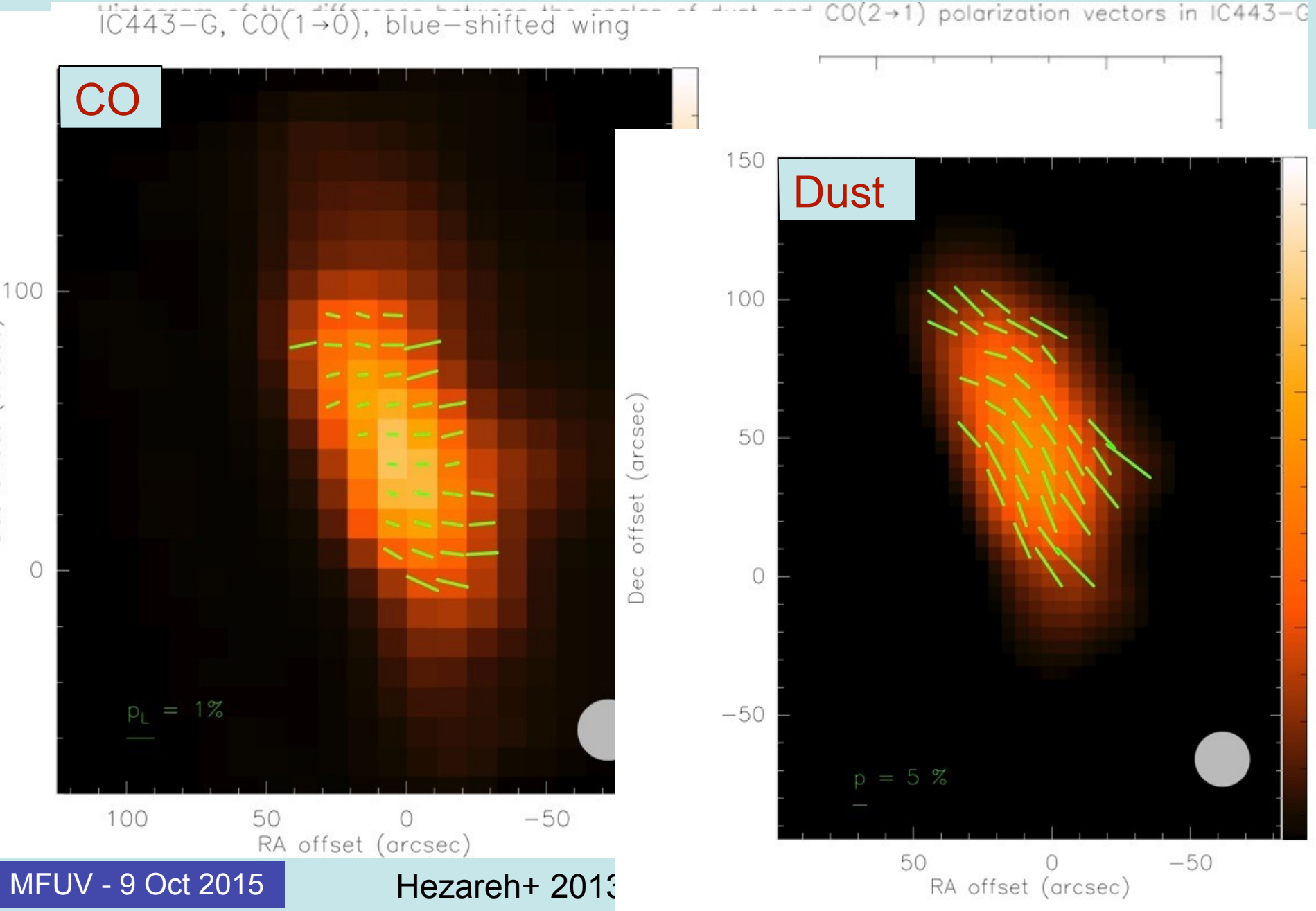
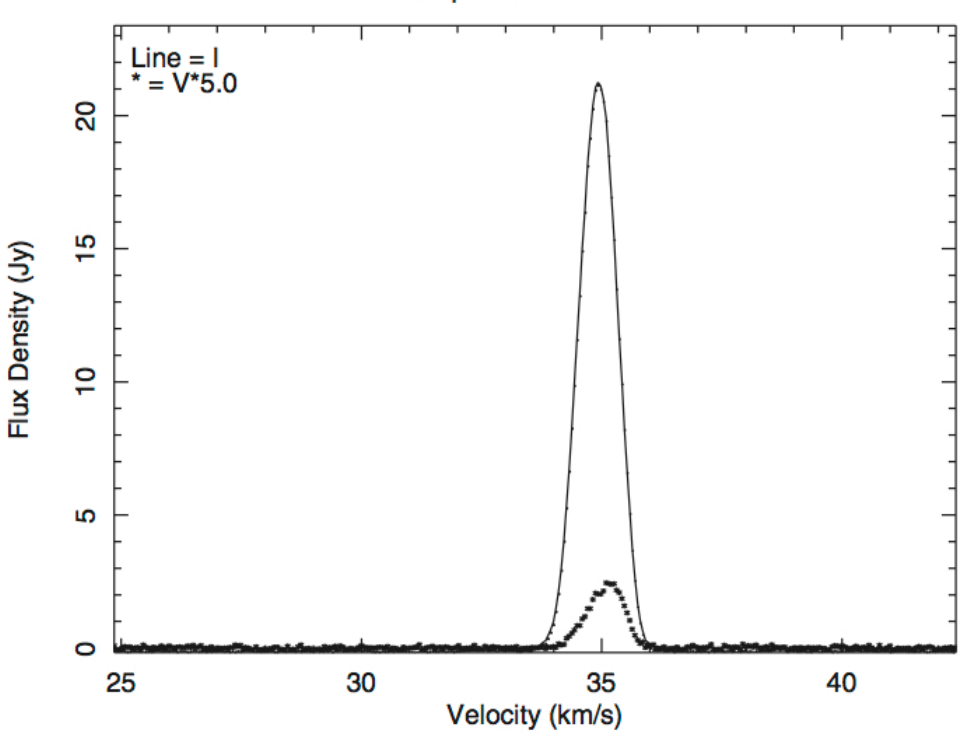
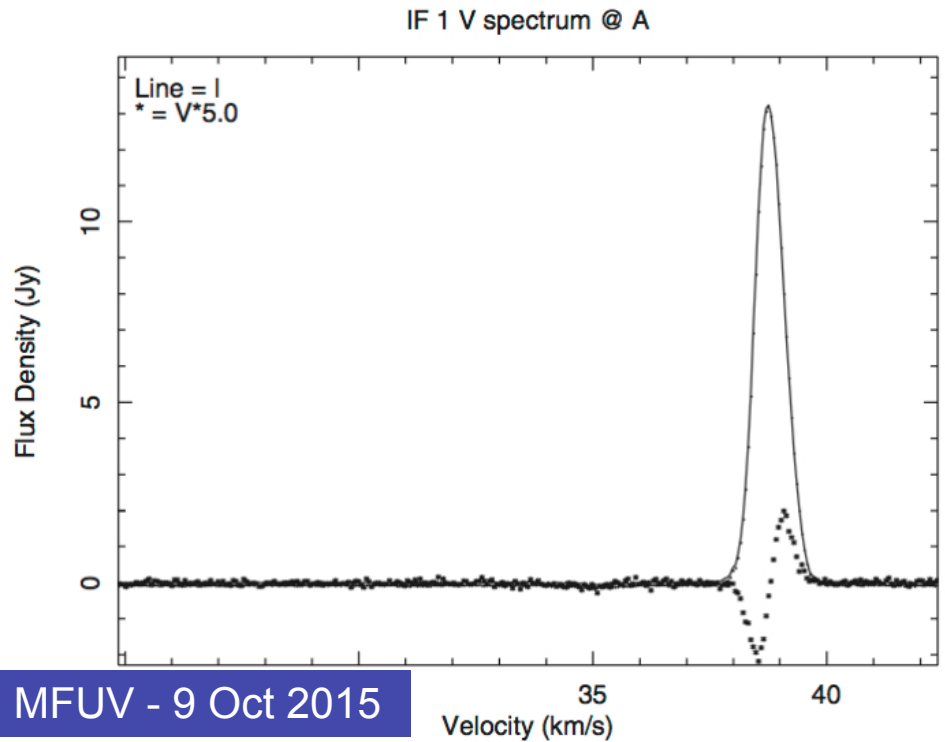


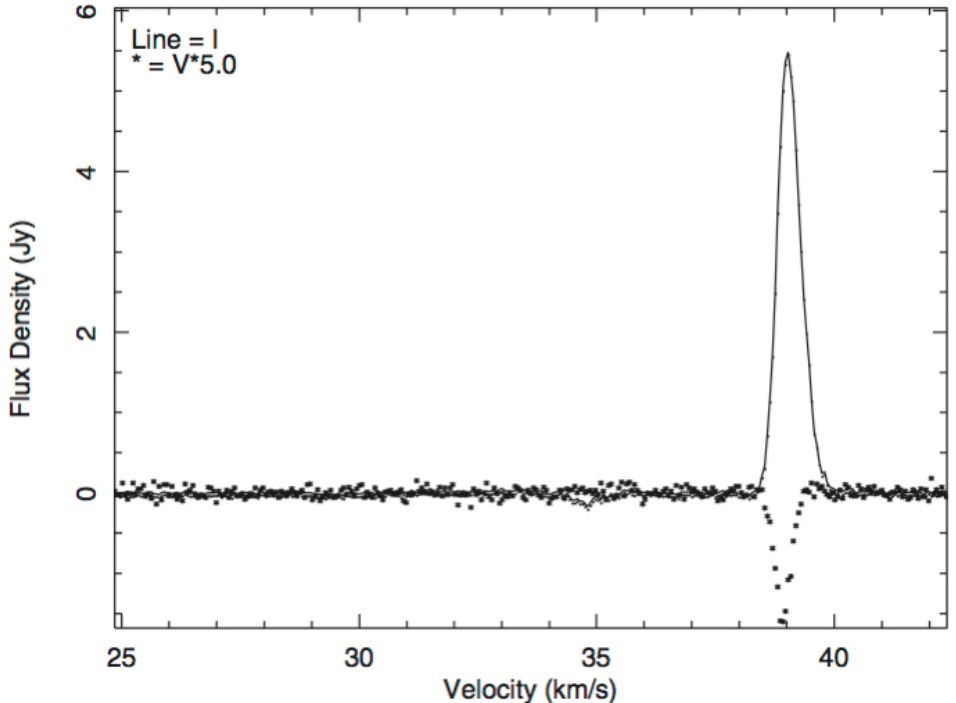
Hezareh+ 2013

SiO Masers in AGB Star IK Tau (with VLBA)

Cotton+ 2011, ApJ, 736, 96



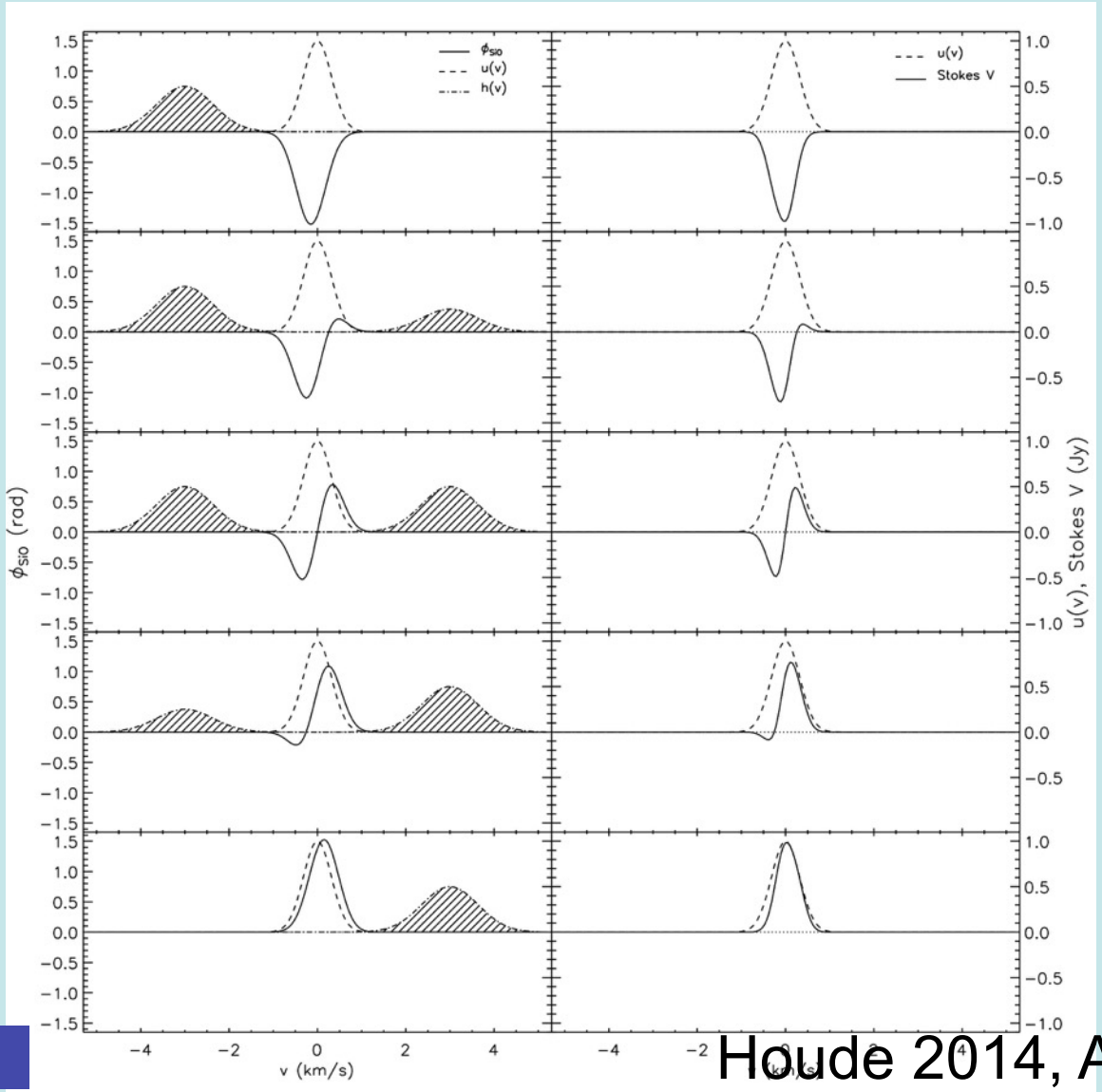




SiO Maser Stokes V Line Profiles

$n_{H_2} = 7.5 \times 10^8 \text{ cm}^{-3}$ $n_{SiO} = 1.2 \times 10^3 \text{ cm}^{-3}$

$T_{ex} = 700 \text{ K}$ $l = 5 \text{ AU}$ $B = 15 \text{ mG}$



Houde 2014, ApJ, 795, 97

Summary

- Detection of non-Zeeman circular polarization in CO.
- We can account for the levels of CP through anisotropic resonant scattering (Orion KL and SNR IC 443(G)).
- Stokes V line profiles are also well accounted for.
- Explains long-standing problem of CP in SiO masers.
- Remains to clearly establish that it is caused by anisotropic resonant scattering.

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

Merci !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