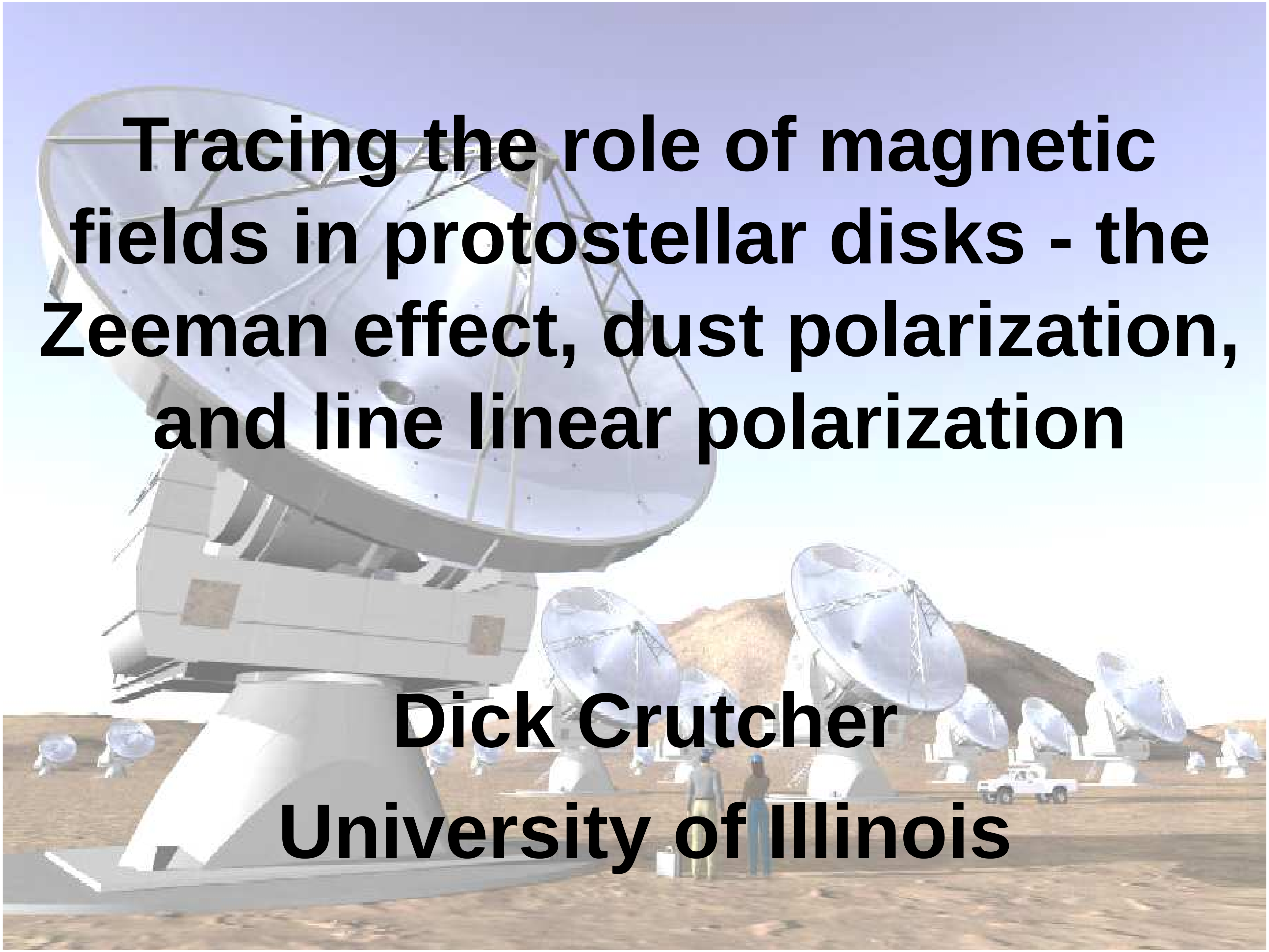
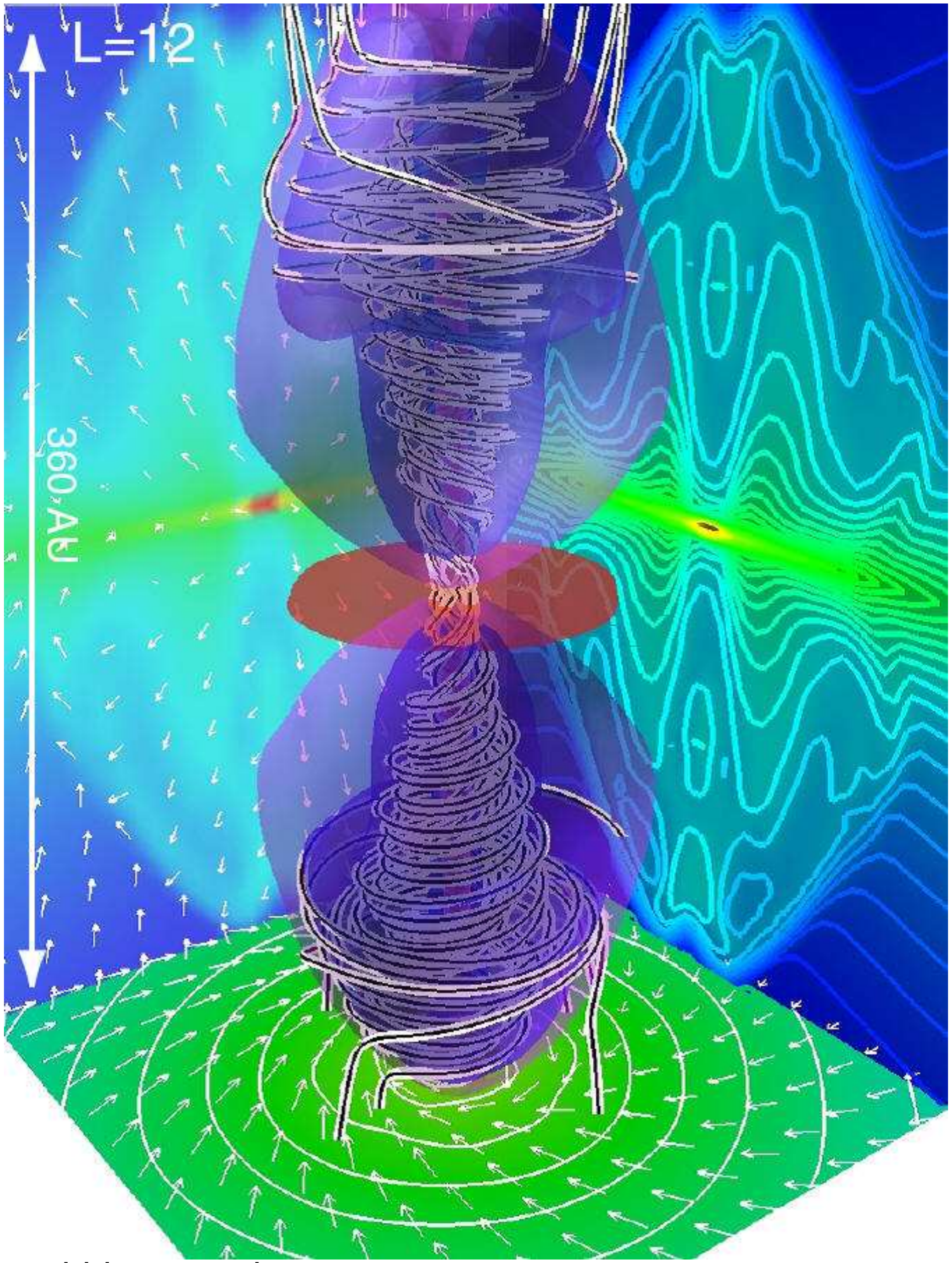


Tracing the role of magnetic fields in protostellar disks - the Zeeman effect, dust polarization, and line linear polarization

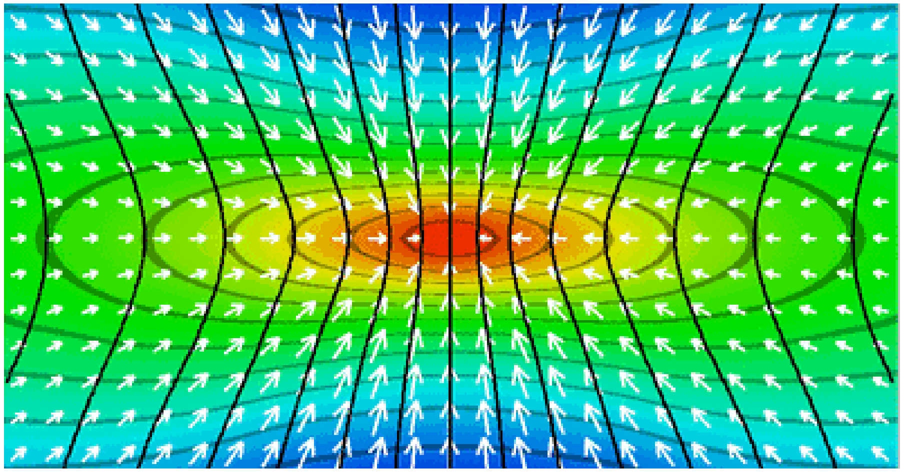
Dick Crutcher

University of Illinois

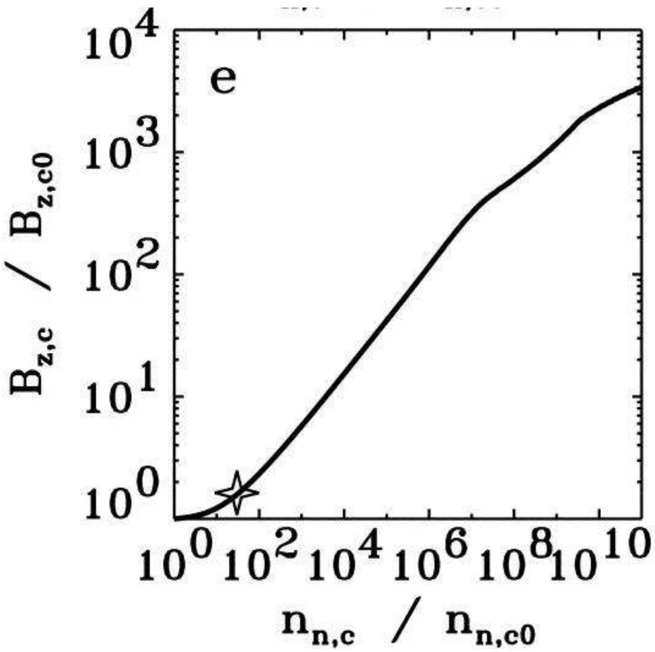
Disk/Jet Simulation



Machida, Inutsuka, Matsumoto 2007

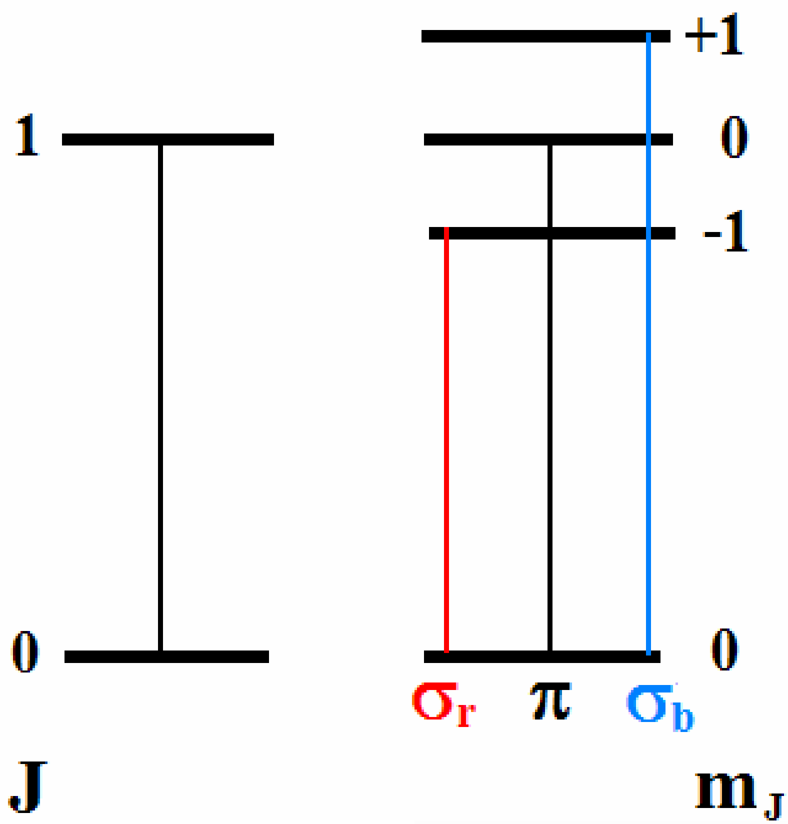


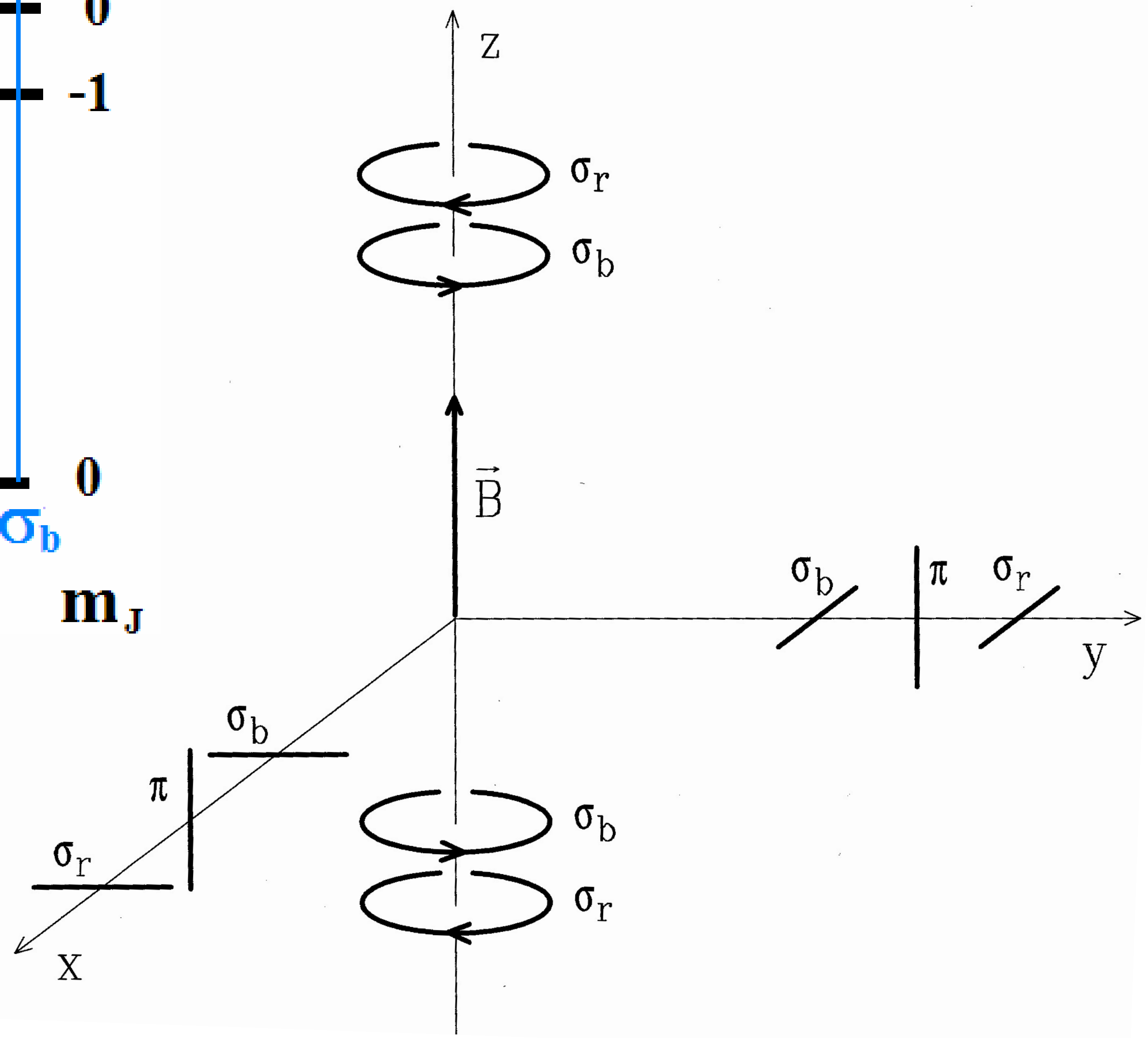
Fiedler & Mouschovias 1993



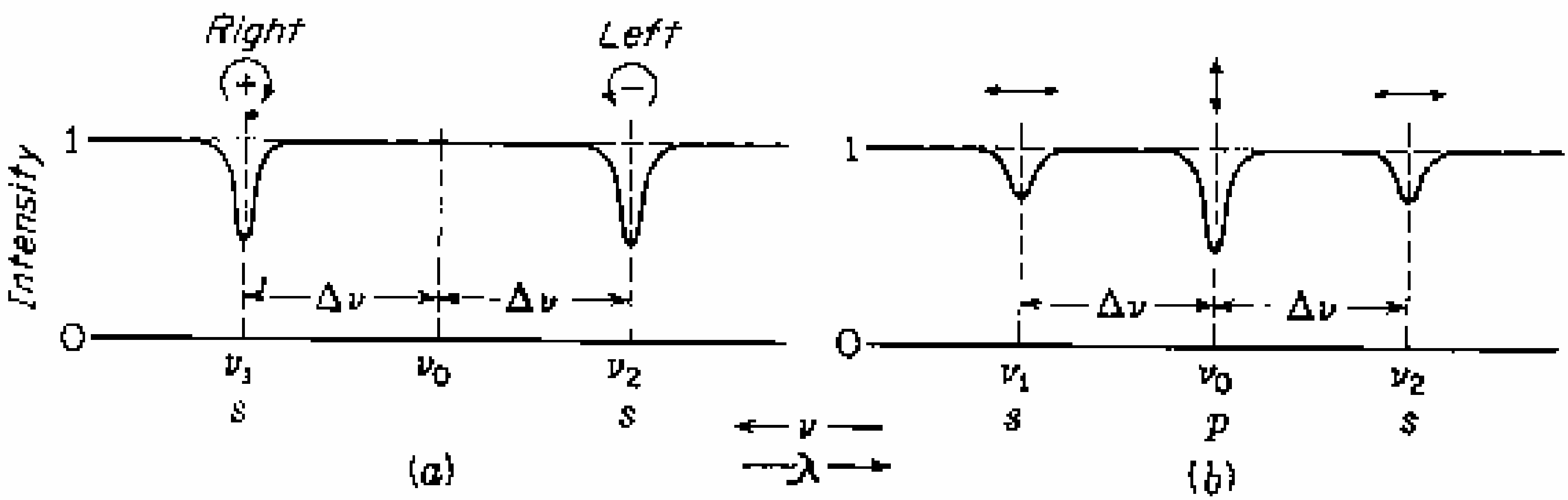
Tassis & Mouschovias 2007

Zeeman Effect (1)

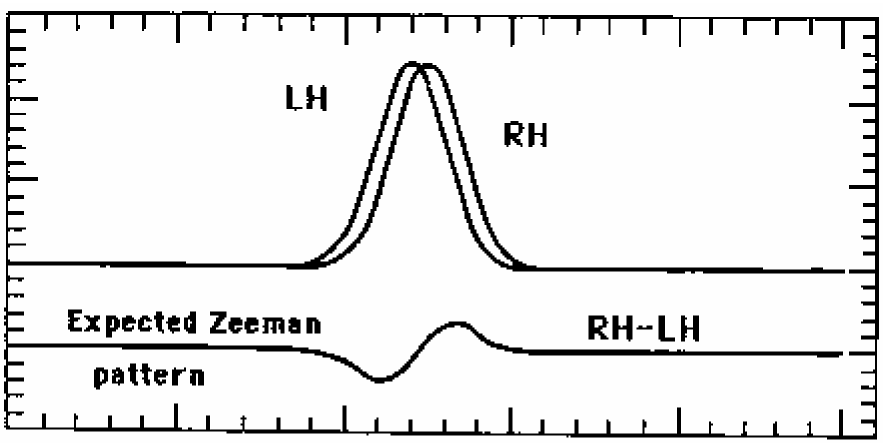




Zeeman Effect (2)



$\Delta\nu_Z = |\mathbf{B}|\, Z,\ Z \approx 1 - 2$ Hz/μG, ($Z_{H\,I} = 1.4$ Hz/μG)



$V = L - R \propto (dI/d\nu)(\Delta\nu_Z \cos\theta) \Rightarrow$

line of sight **B**

Q or $U \propto (d^2I/d\nu^2)(\Delta\nu_Z \sin\theta)^2 \Rightarrow$

plane of sky **B** (not really)

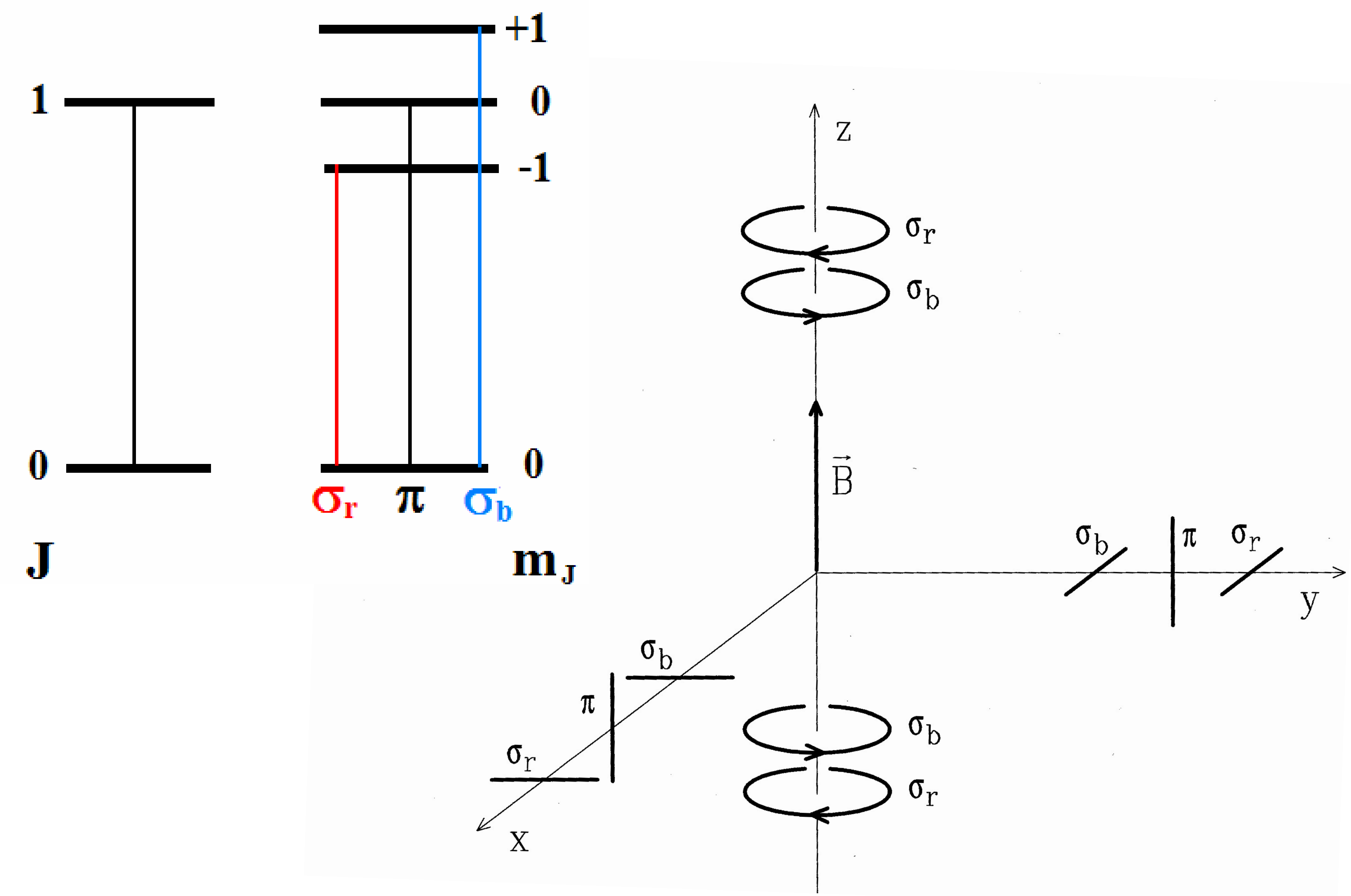
$(dI/d\nu)\Delta\nu_Z \propto I\,(\Delta\nu_Z / \Delta\nu_{FWHM})$

Zeeman Effect (3)

Species	Transition	ν (GHz)	Z (Hz/μG)
CO, CS, HCN, …	various	various	(few) x 10^{-4}
CCH	N,J = 1,½ $\rightarrow$ 0,½	87.4	2.8
SO	N,J = 2,3 $\rightarrow$ 1,2	99.3	1.0
SO	N,J = 3,4 $\rightarrow$ 2,3	138.2	0.8
SO	N,J = 4,3 $\rightarrow$ 3,2	159.0	1.0
SO	N,J = 5,6 $\rightarrow$ 4,5	220.0	0.5
SO	N,J = 2,1 $\rightarrow$ 1,2	236.5	1.7
CN	N,J = 1,$\frac{3}{2}$ $\rightarrow$ 0,½	113.5	2.2
CN	N,J = 2,$\frac{3}{2}$ $\rightarrow$ 1,$\frac{3}{2}$	226.3	2.6

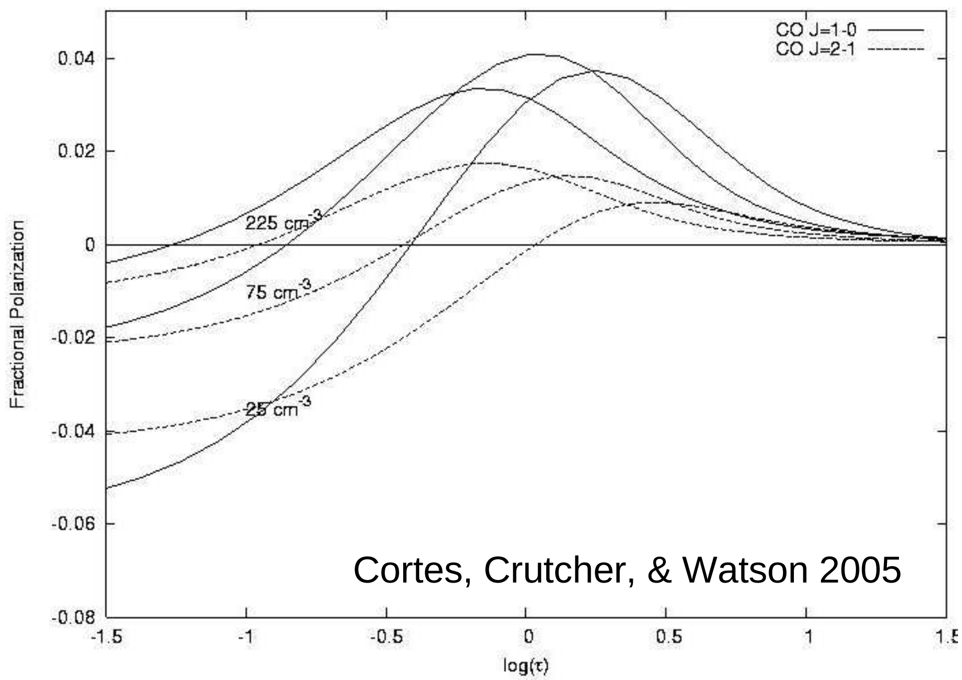
Bel & Leroy 1989, 1998

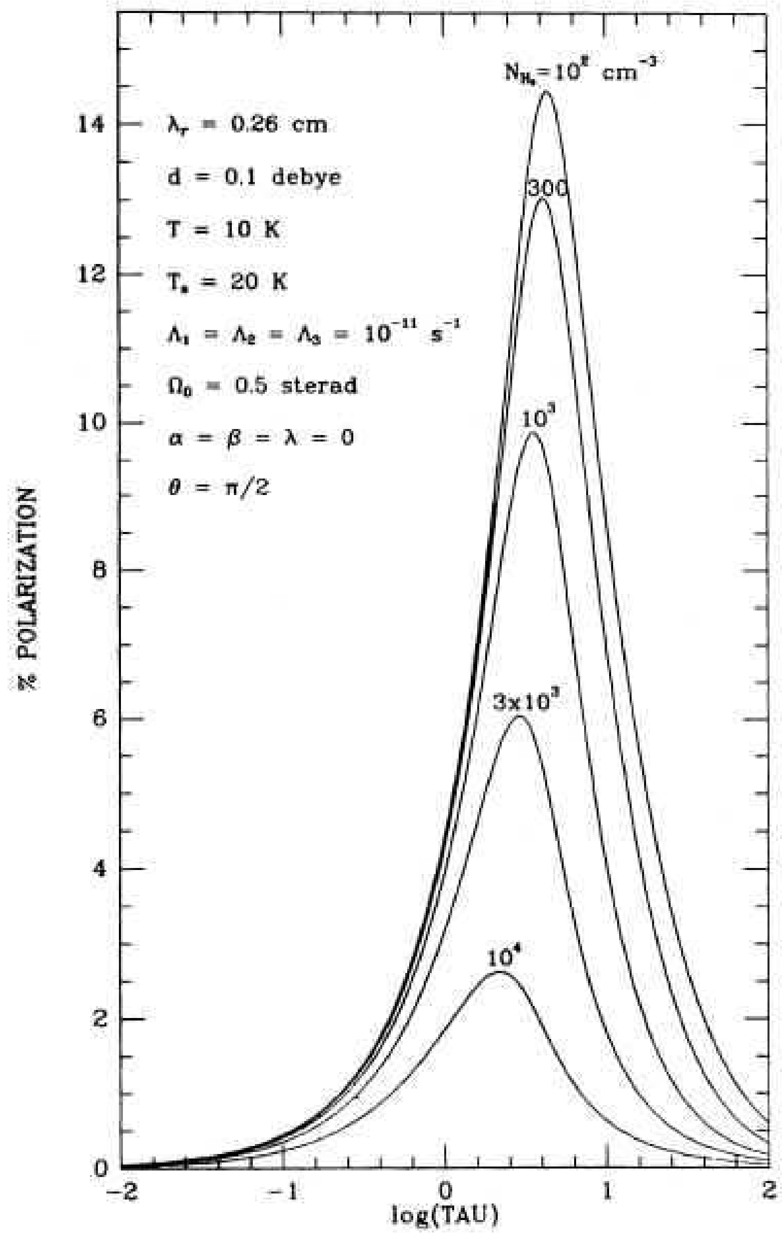
Goldreich-Kylafis Effect (1)



Goldreich-Kalafis Effect (2)

- Local anisotropy in line optical depth ⇒
- anisotropy in radiation field ⇒
- non-LTE population of magnetic sublevels ⇒
- linear polarization ⊥ or || **B**



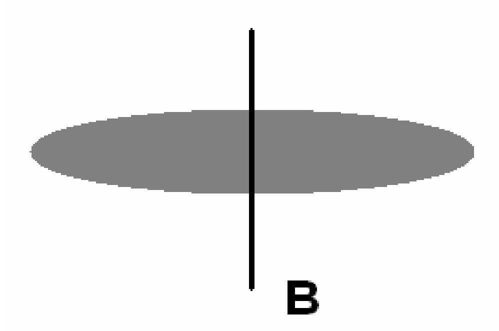


Kylafis 1983

Dust Polarization

Polarized emission from paramagnetic grains

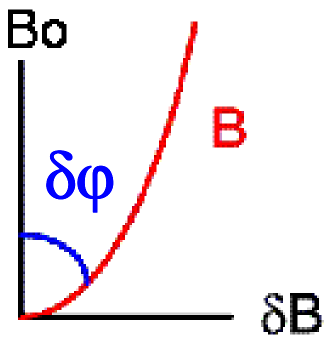
- grain alignment with minor axis || **B**



- linear polarization ⊥ **B** ⇒ morphology of B_{pos}

- polarization percentage independent of the strength of the magnetic field, so no direct measurement of field strength

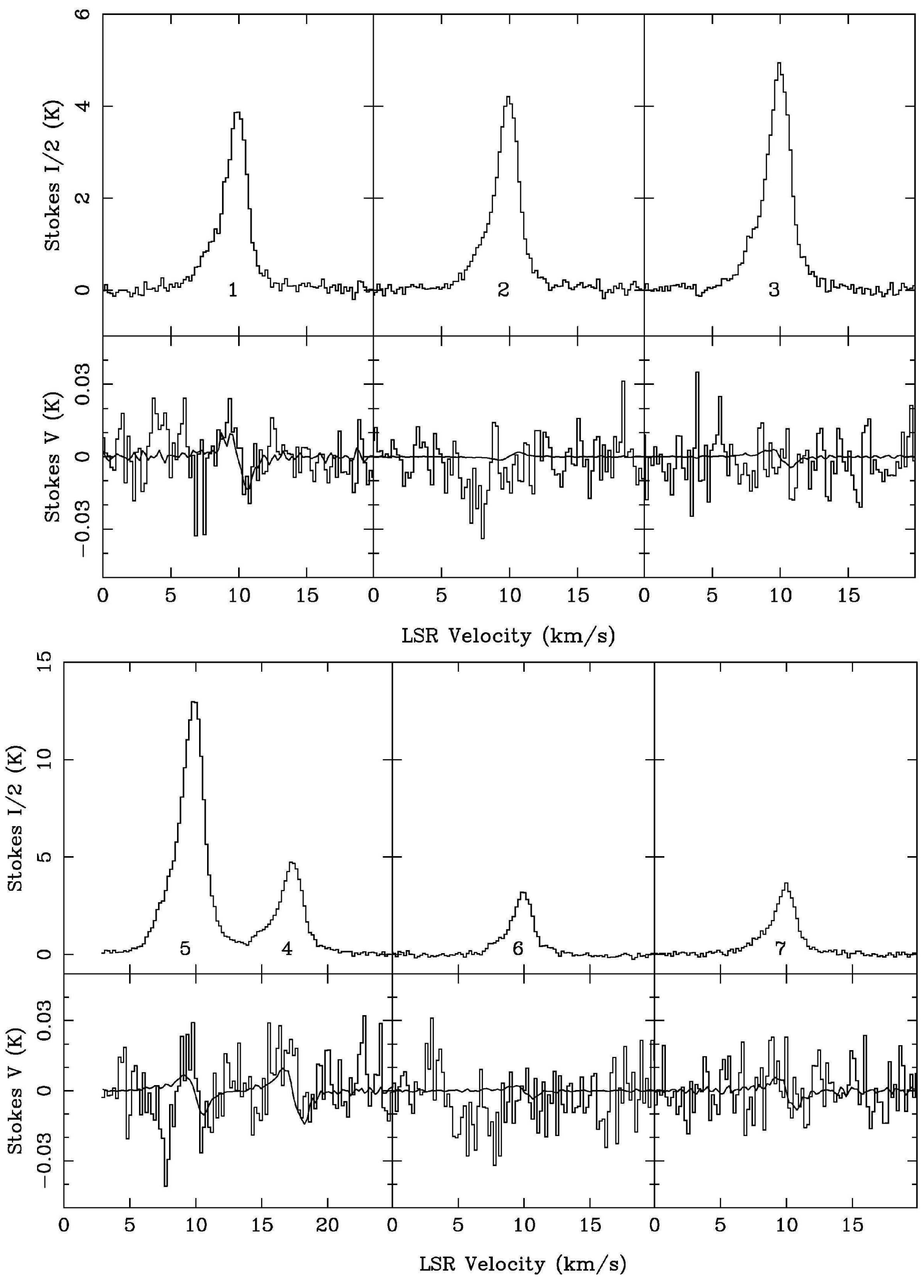
- indirectly (Chandrasekhar & Fermi):

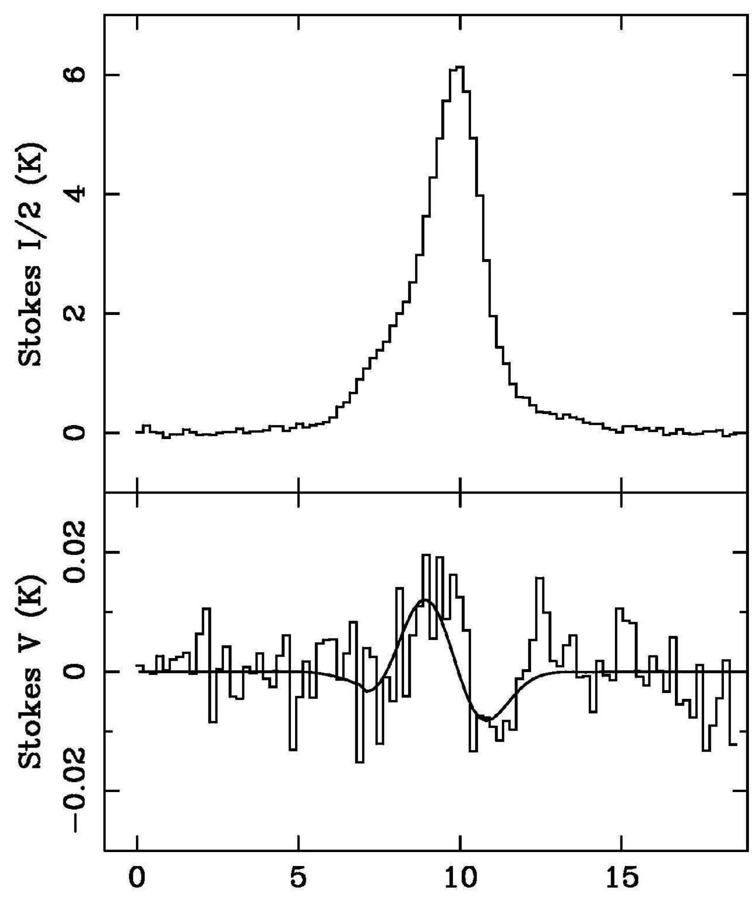


$\delta V \approx \delta B/(4\pi\rho)^{1/2}$, $\delta\varphi \approx \delta B/B_{pos}$

$\therefore\ B_{pos} \approx 0.5(4\pi\rho)^{1/2}\ \delta V_{los}/\delta\varphi$

CN 1-0 (113 GHz) Zeeman (IRAM 30-m)

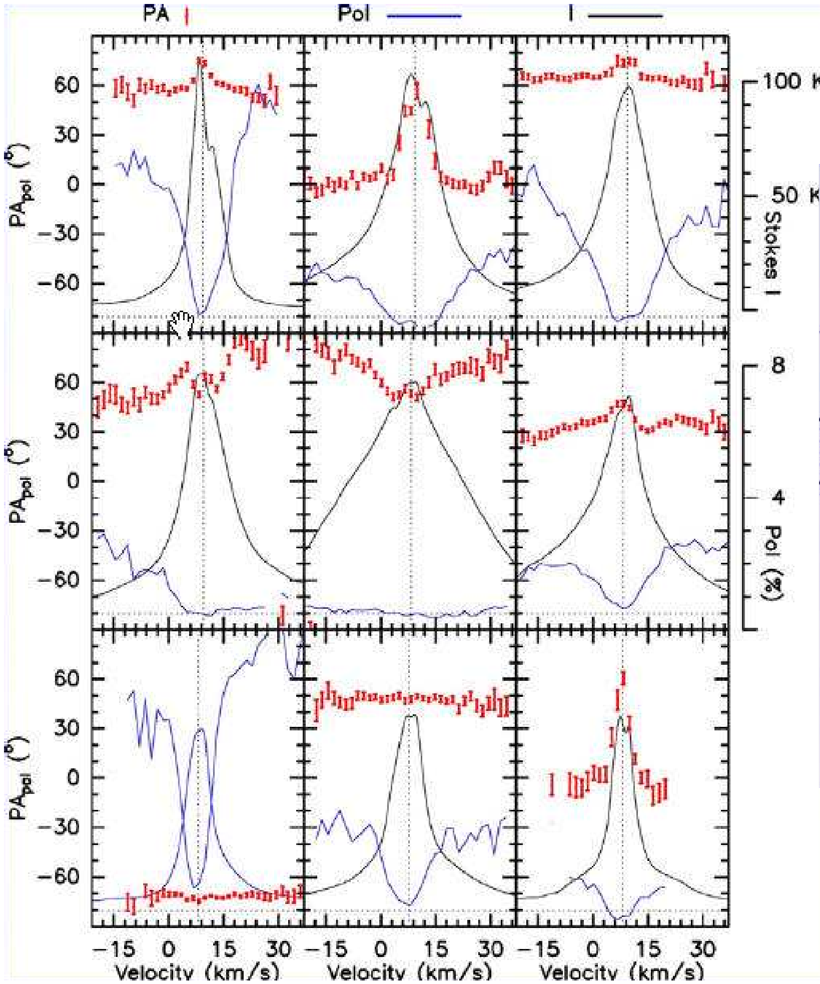


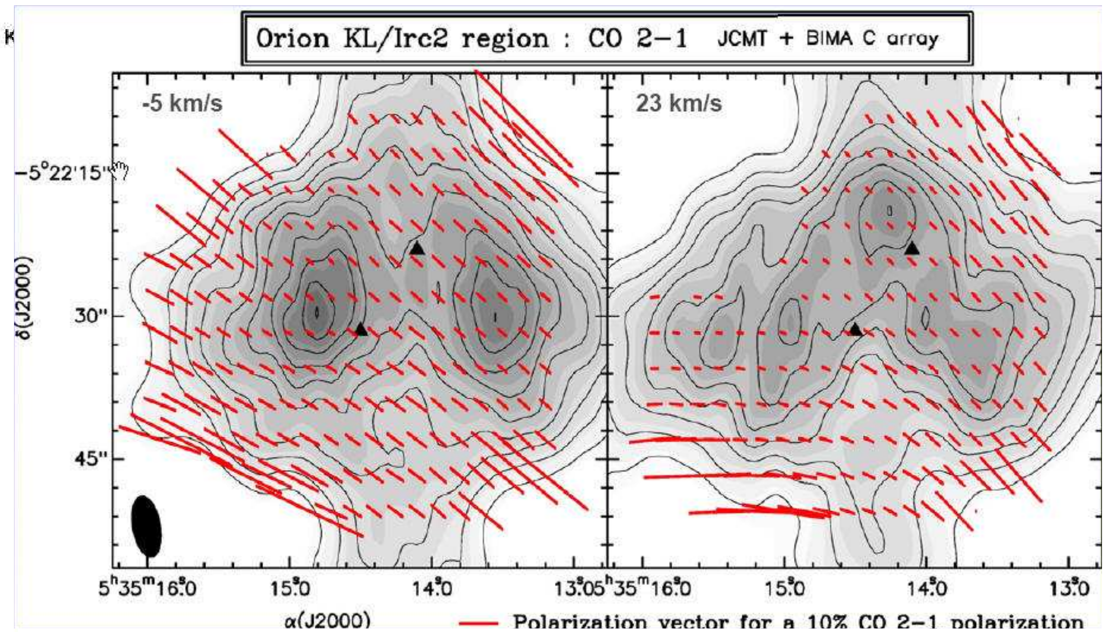


$B_{LOS} = -0.36 \pm 0.08$ mG

Crutcher et al. 1999

CO Linear Polarization



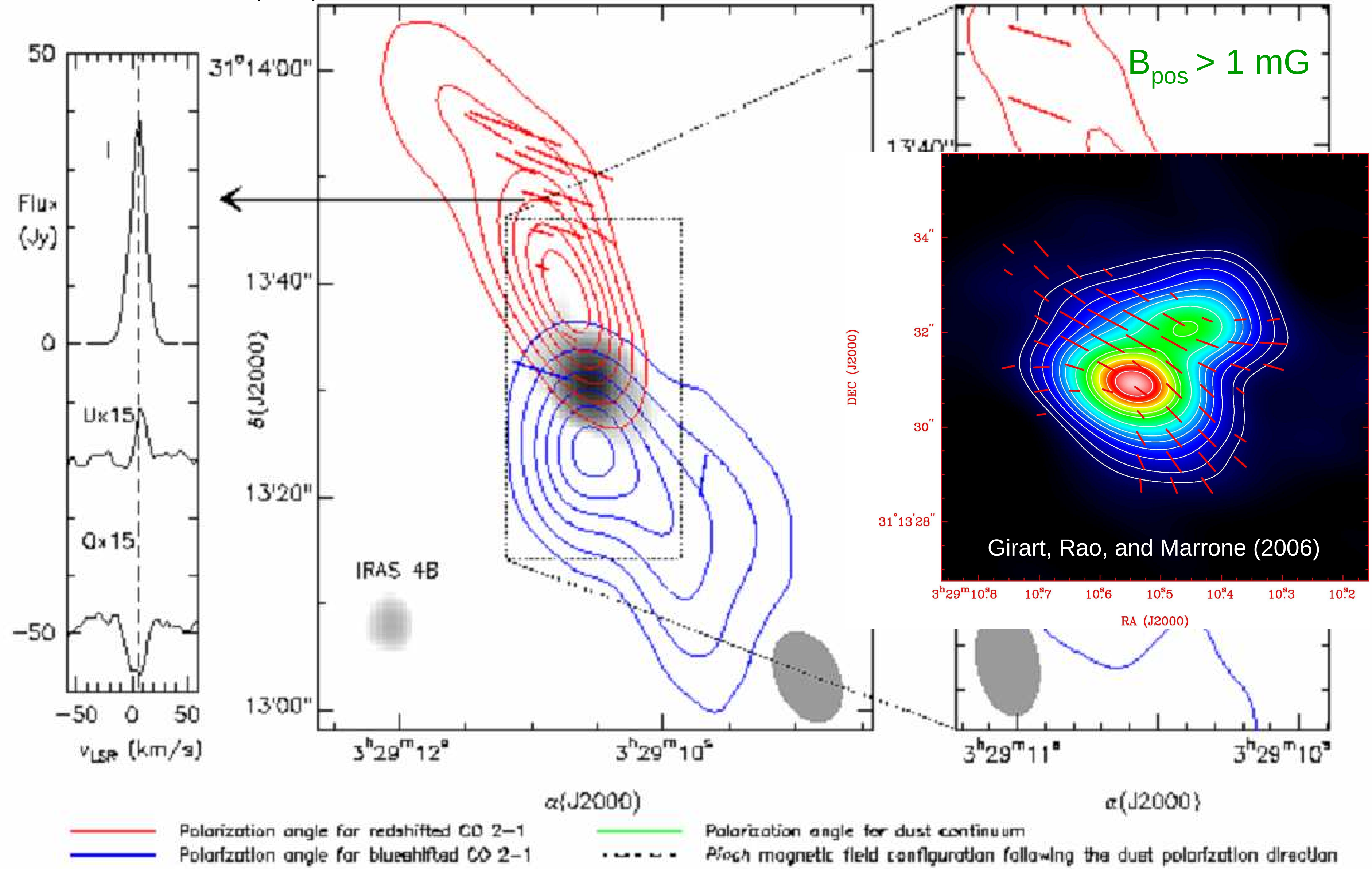


Girart, Greaves, Crutcher & Lai 2004

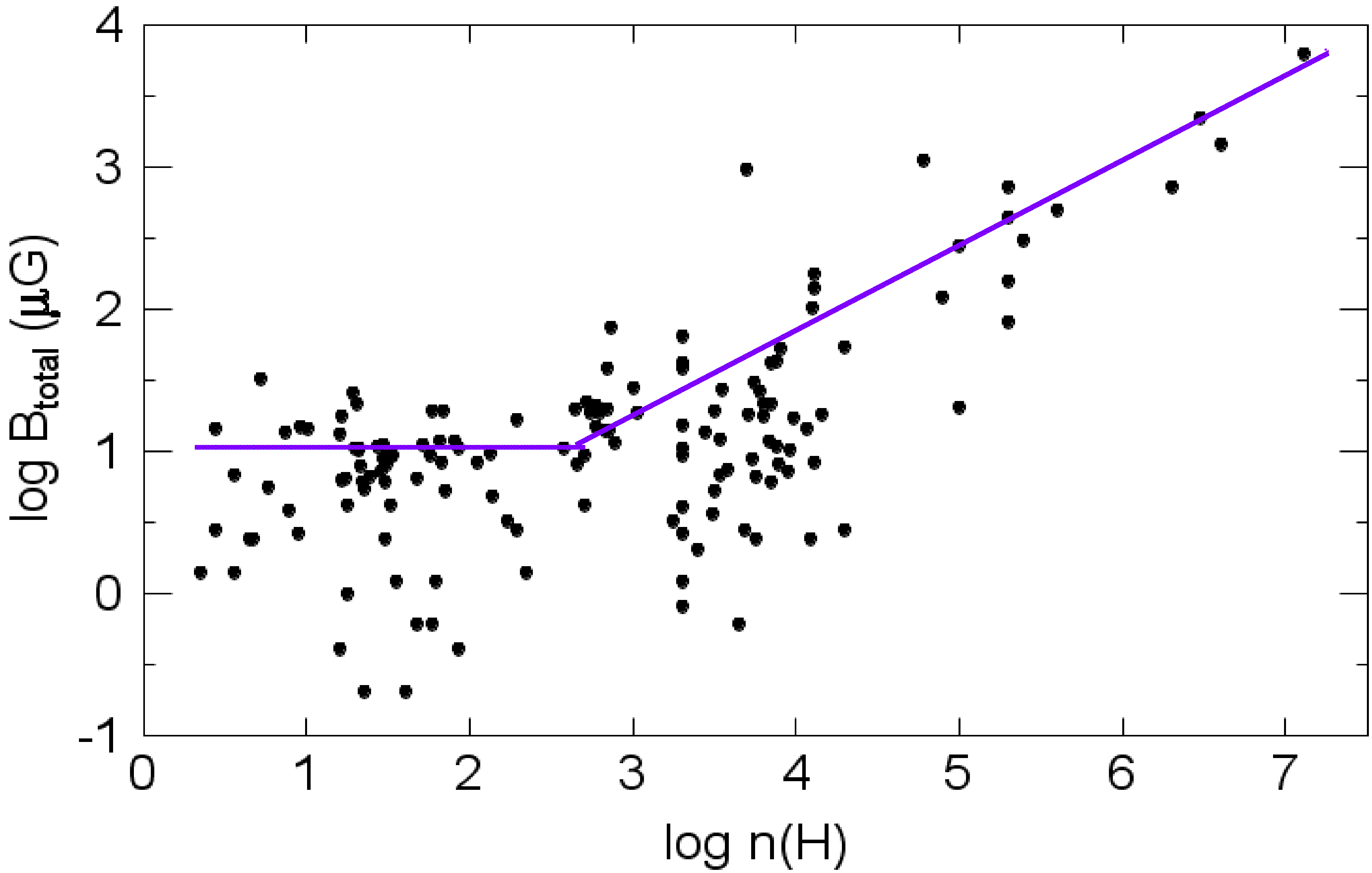
NGC1333 IRAS4

Girart, Crutcher & Rao (1999)

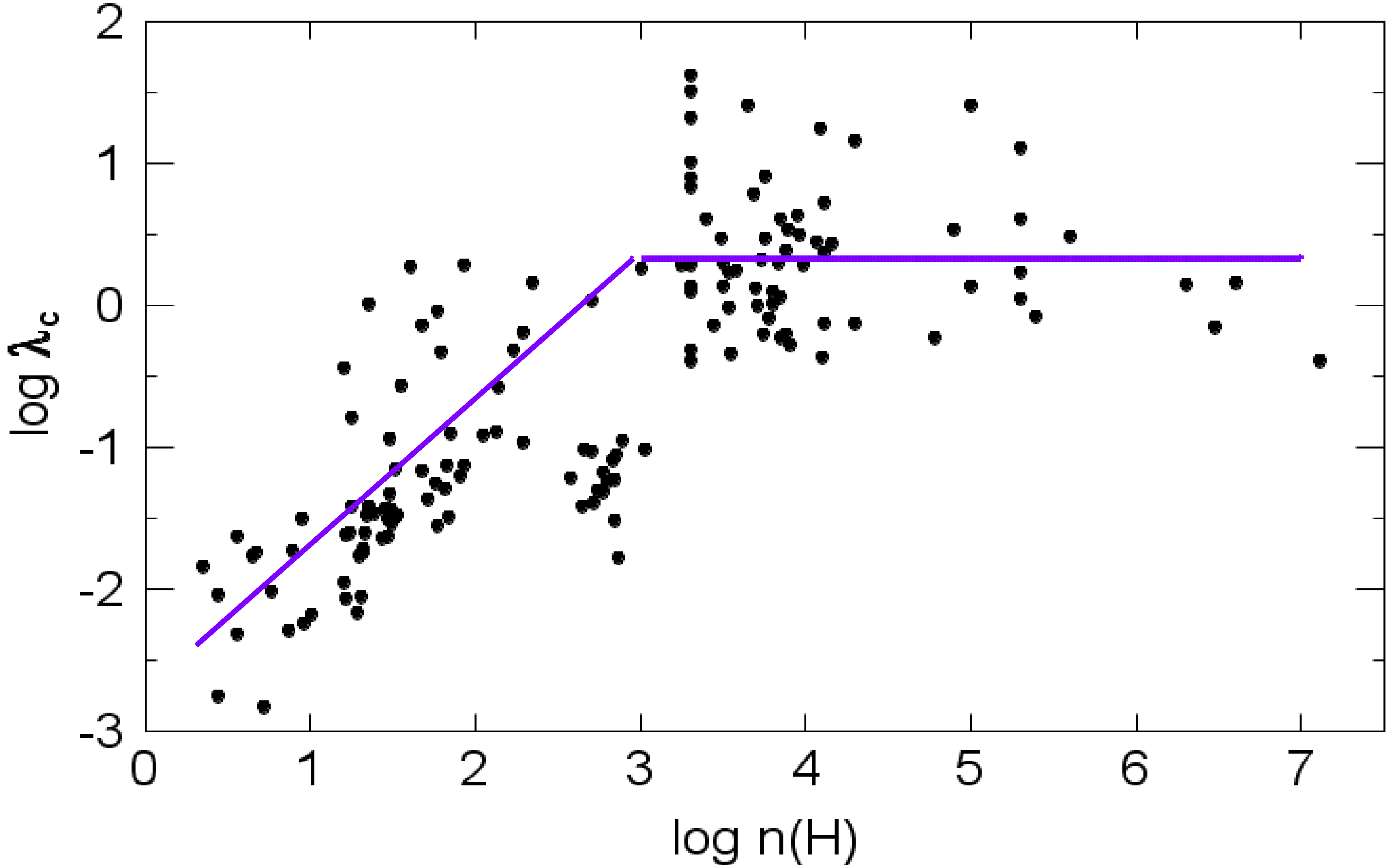
Dust emission (230 GHz) and CO 2-1 emission (BIMA)



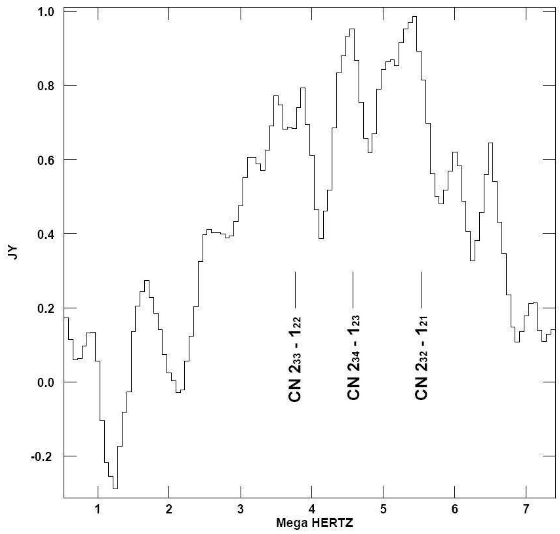
Results for Field Strength

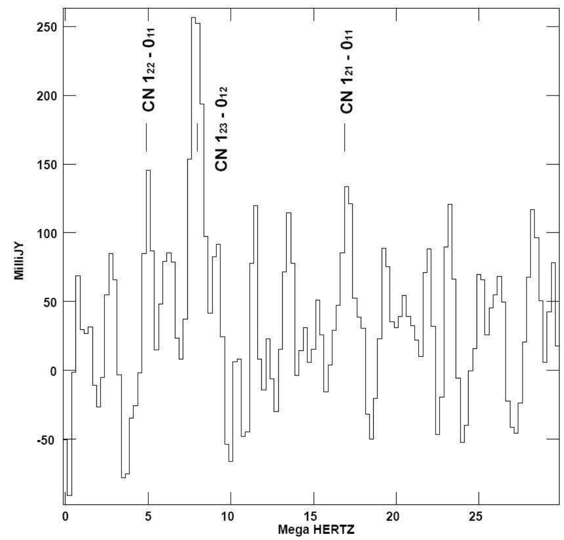


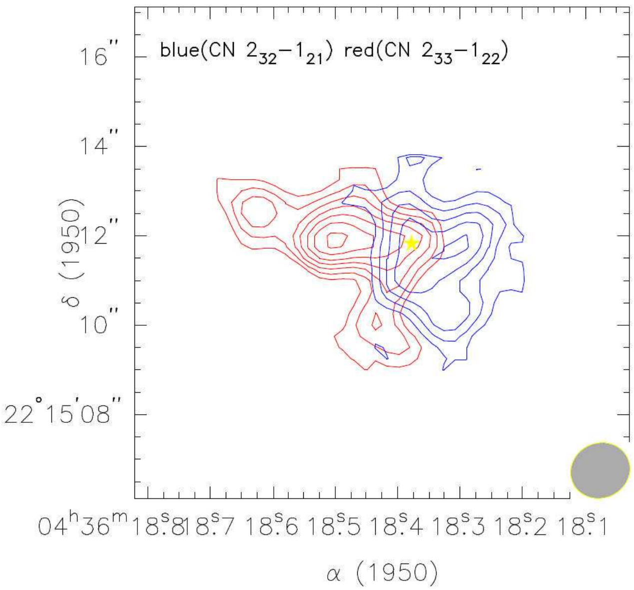
Results for Mass/Flux

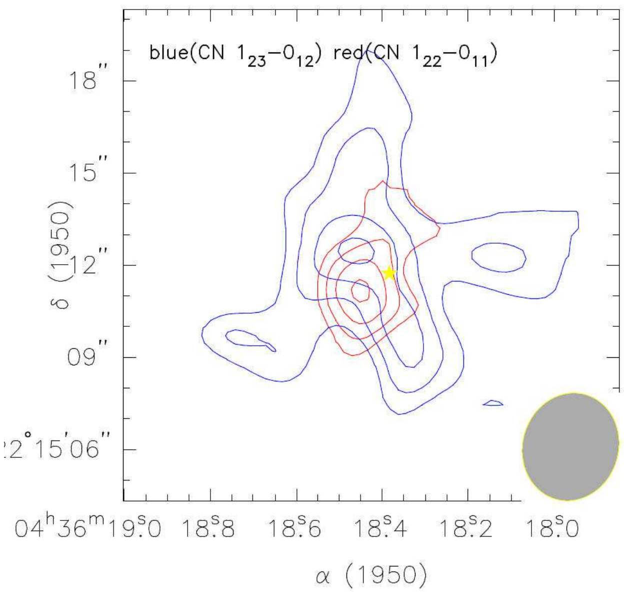


CN in LkCa 15 Disk









major axis pa: 64º

mass: 0.18 M□

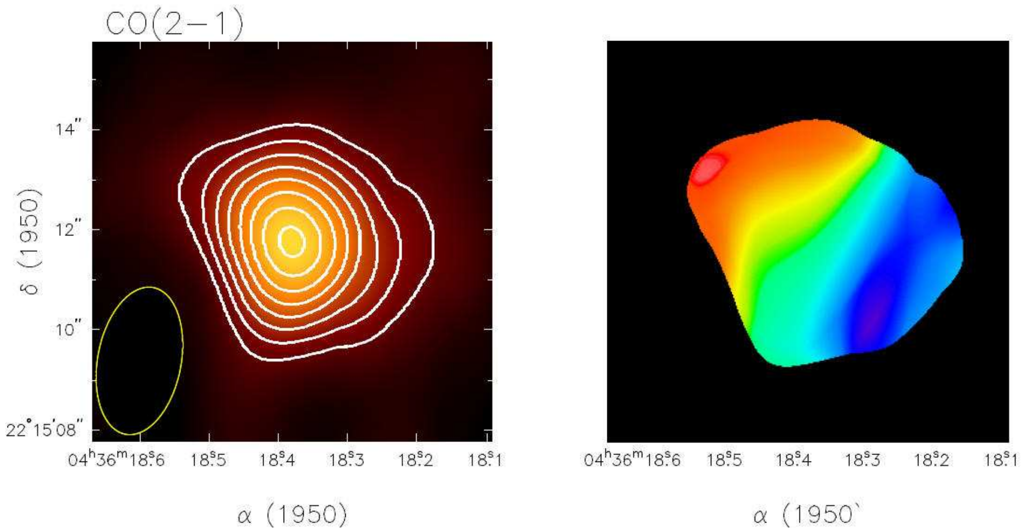
R_{out}: 435 au

ALMA 1-σ sensitivity after 6 hours:

B ≈ 1 mG

Chunhua Qi PhD thesis, 2001

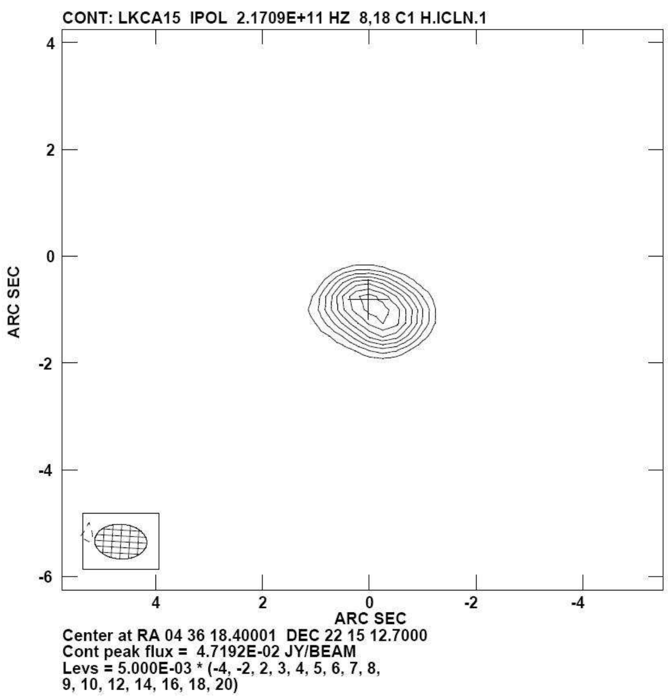
CO & continuum in LkCa 15 Disk



CO ~ 10x stronger than CN

$\Delta T/T_L \sim 10^{-4}$

S/N ~ 100 after 6 hrs



$\Delta S_\nu / S\nu \sim 10^{-4}$

S/N ~ 100 after 6 hrs

Chunhua Qi PhD thesis, 2001

Magnetic Field Mapping in LkCa 15 Disk

1) Zeeman: $B \approx 1$ mG

2) CO linear polarization: S/N ~ 100

3) Dust linear polarization: S/N ~ 100

All 3 observations can be done simultaneously!!!

Above was for 3 mm; S/N will be higher at 1.3 and 0.85 mm


"That's all Folks!"