Magnetic Fields in Star Forming Clouds

Richard M. Crutcher, University of Illinois

Some Collaborators:
Tom Troland, University of Kentucky
Edith Falgarone, Ecole Normale Superieure
Paulo Cortes, University of Chile
Shih-Ping Lai, National Tsing Hua University
Ramprasad Rao, SubMillimeter Array
Derek Ward-Thompson, Cardiff University
Philippe André, CEA
Jason Kirk, Cardiff University
Doug Roberts, Northwestern University
Josep Girart, University of Barcelona
Carl Heiles, UC Berkeley
Ilya Kazès, Meudon
Crystal Brogan, NRAO
Anuj Sarma, DePaul University
Miller Goss, NRAO
Alyssa Goodman, Harvard University
Phil Myers, CfA

The Central Question

Are magnetic fields significant and/or crucial to,
or are they insignificant and a distraction from,
understanding the central physics of star formation?

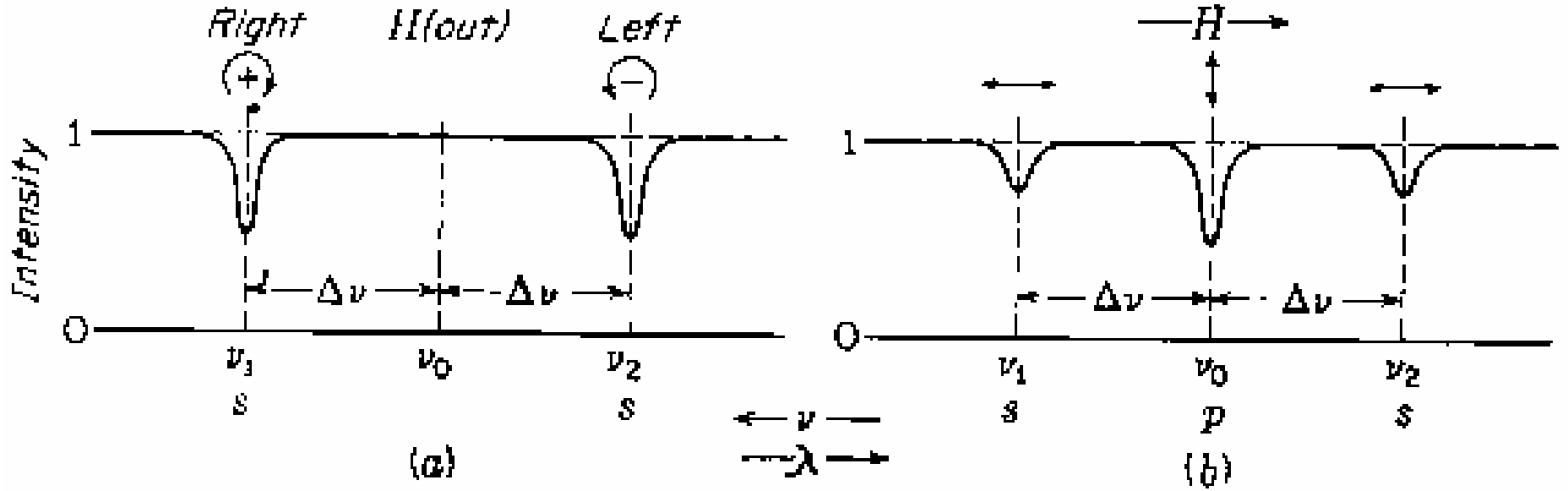
Hints may come from…

- estimates of timescale of star formation
- super-Alfvenic simulations that seem to work
- evidence for externally triggered star formation

However, the direct answer must come from observations of magnetic fields and their interpretation in the context of star formation theory:

- ratio of gravity to magnetic support: M/Φ

Zeeman Effect



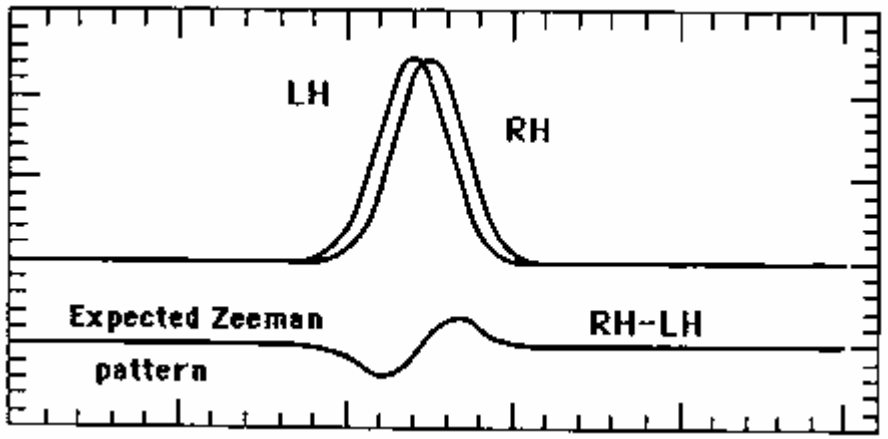
$$\Delta\nu_Z = |\mathbf{B}|\, Z,\ Z \approx 1 - 2\ \mathrm{Hz}/\ \mu\mathrm{G},\ \ (Z_{HI} = 1.4\ \mathrm{Hz}/\mu\mathrm{G})$$

Q or U $\propto (d^2I/d\nu^2)(\Delta\nu_Z sin\theta)^2 \Rightarrow$ plane of sky **B** (not really)

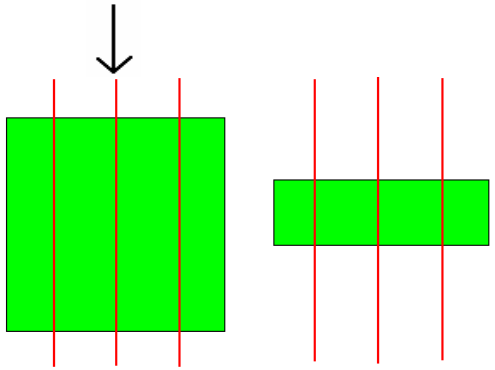
$\propto (\Delta\nu_Z/\mathrm{linewidth})^2$

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

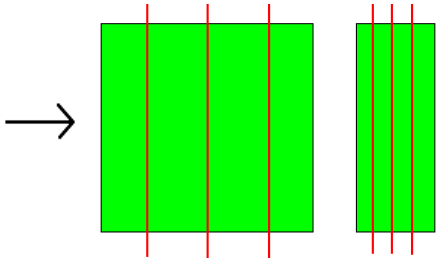
line of sight $\bar{\mathbf{B}}$; $B_{total} = 2 \times B_{los}$



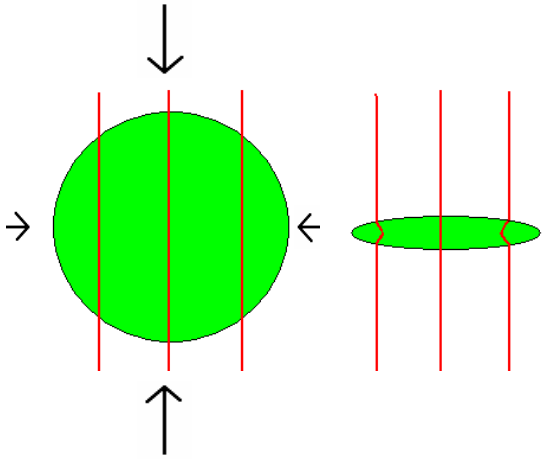
Scaling of B with ρ: $B \propto \rho^{\kappa}$



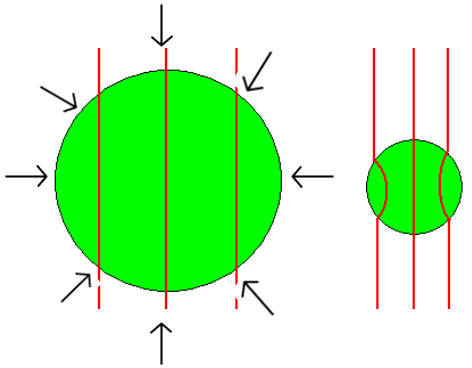
$B \propto \rho^{0}$



$B \propto \rho^{1}$



$B \propto \sigma\rho^{1/2}$



$B \propto \rho^{2/3}$

Mass-to-Flux Ratio: M/Φ

mass/flux ratio ≡ gravitational collapse / magnetic support

- **Uniform disk** Nakano & Nakamura 1978

$$\left(\frac{M}{\Phi}\right)_{critical} = \frac{1}{2\pi\sqrt{G}}$$

- **Observing M/Φ**

$$\frac{M_{observed}}{\Phi_{observed}} \propto \frac{N(H_2)}{B}$$

- **λ definition**

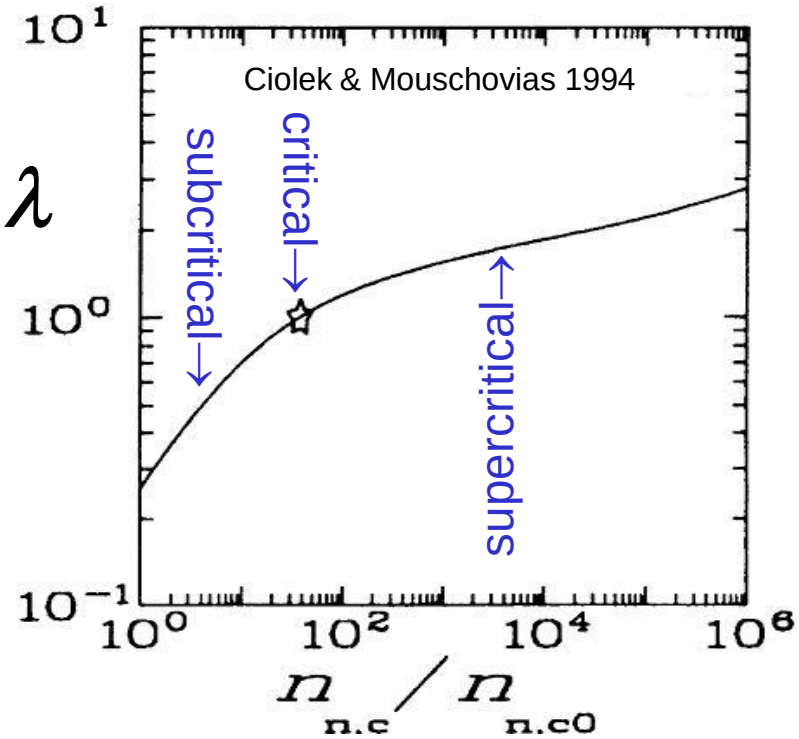
$$\lambda \equiv \frac{(M/\Phi)_{observed}}{(M/\Phi)_{critical}}$$

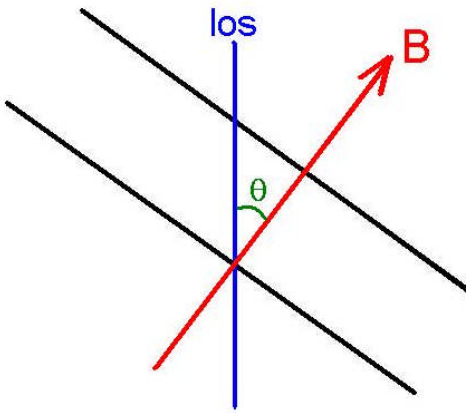
- **Geometry correction**

$\lambda_C = \lambda_{observed}/2$ B_{los} only

$\lambda_C = \lambda_{observed}/4$ B_{los} + disk, uncorrelated

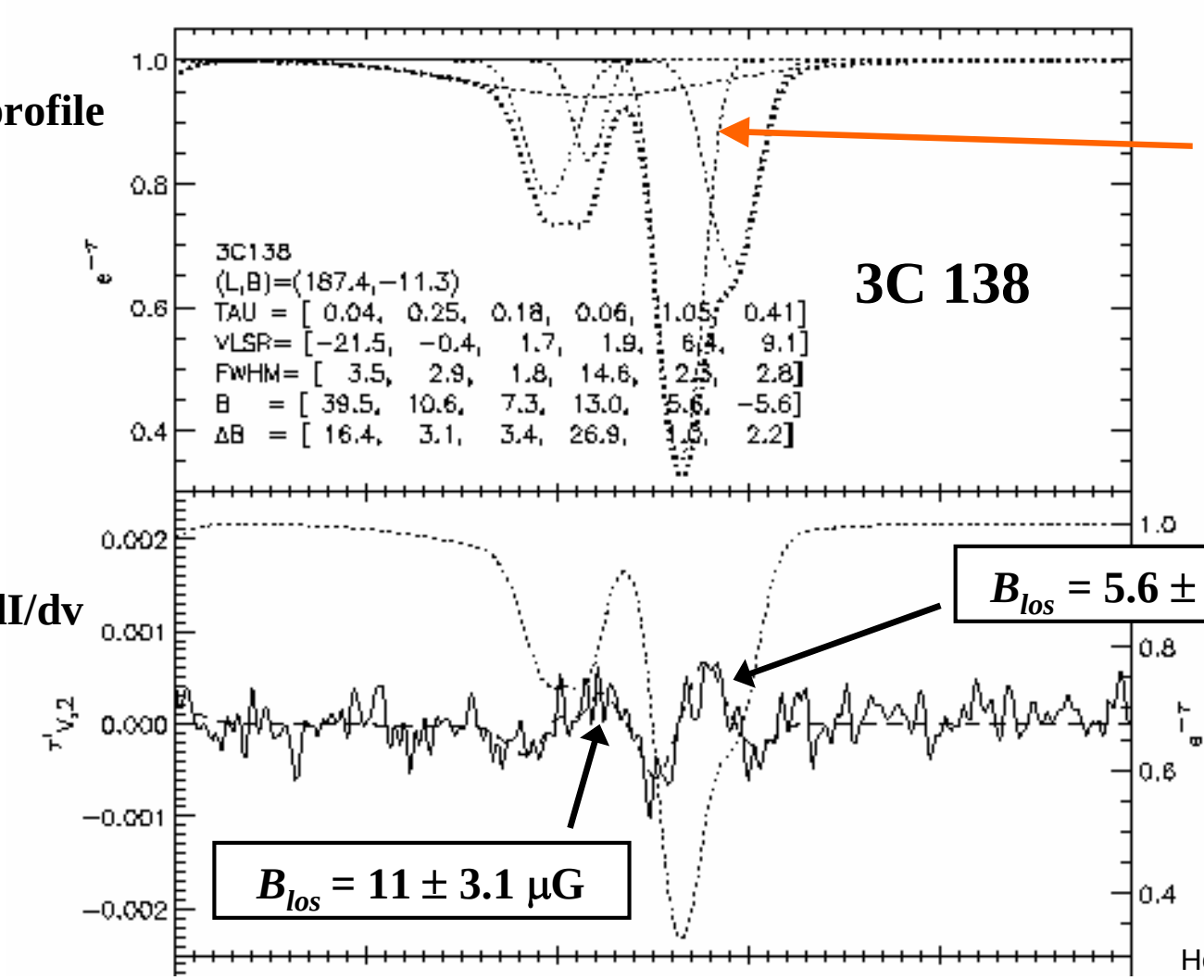
$\lambda_C = \lambda_{observed}/3$ B_{los} + disk morphology





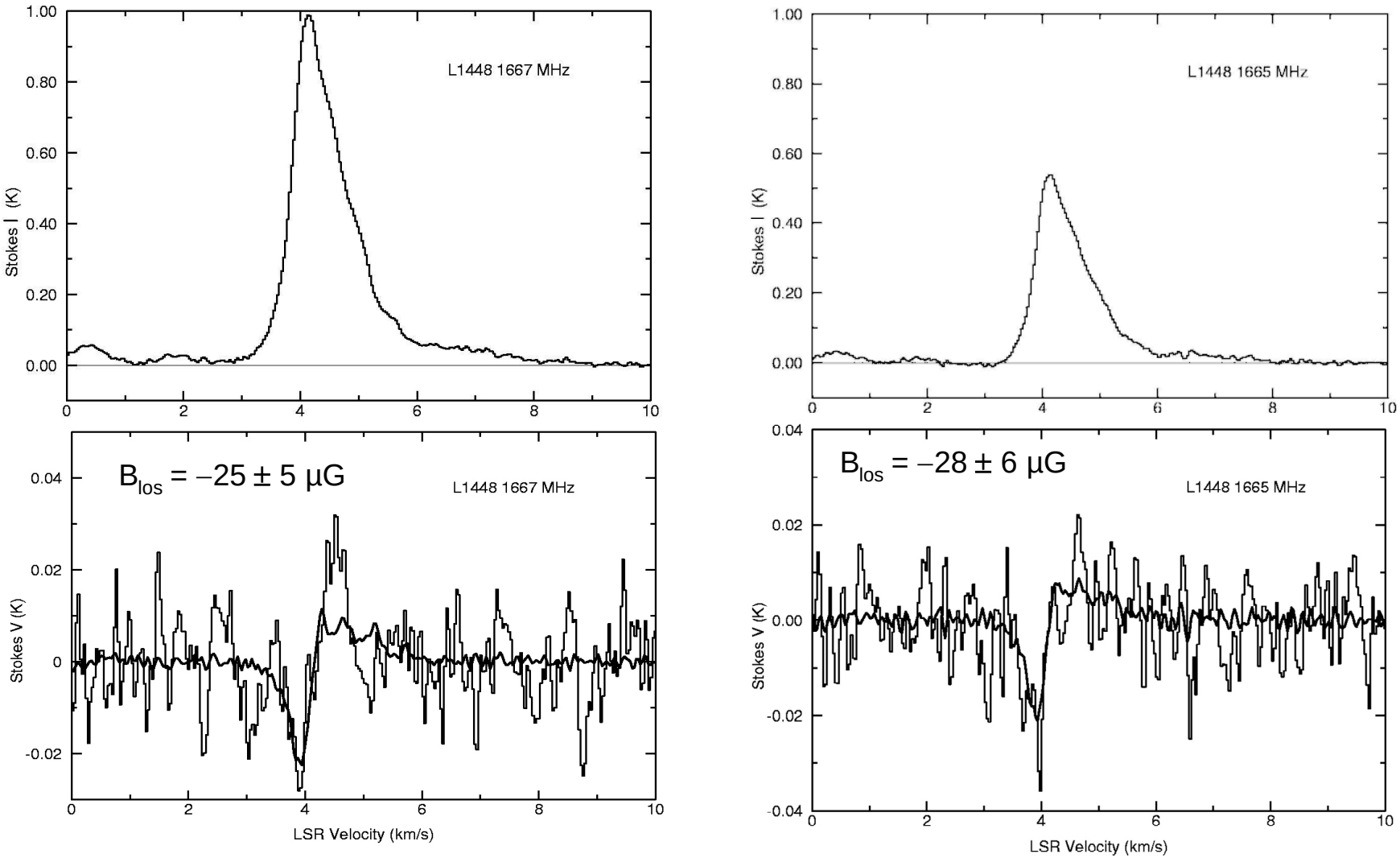
Diffuse Cloud (H I Zeeman)

Arecibo "Millennium" Survey



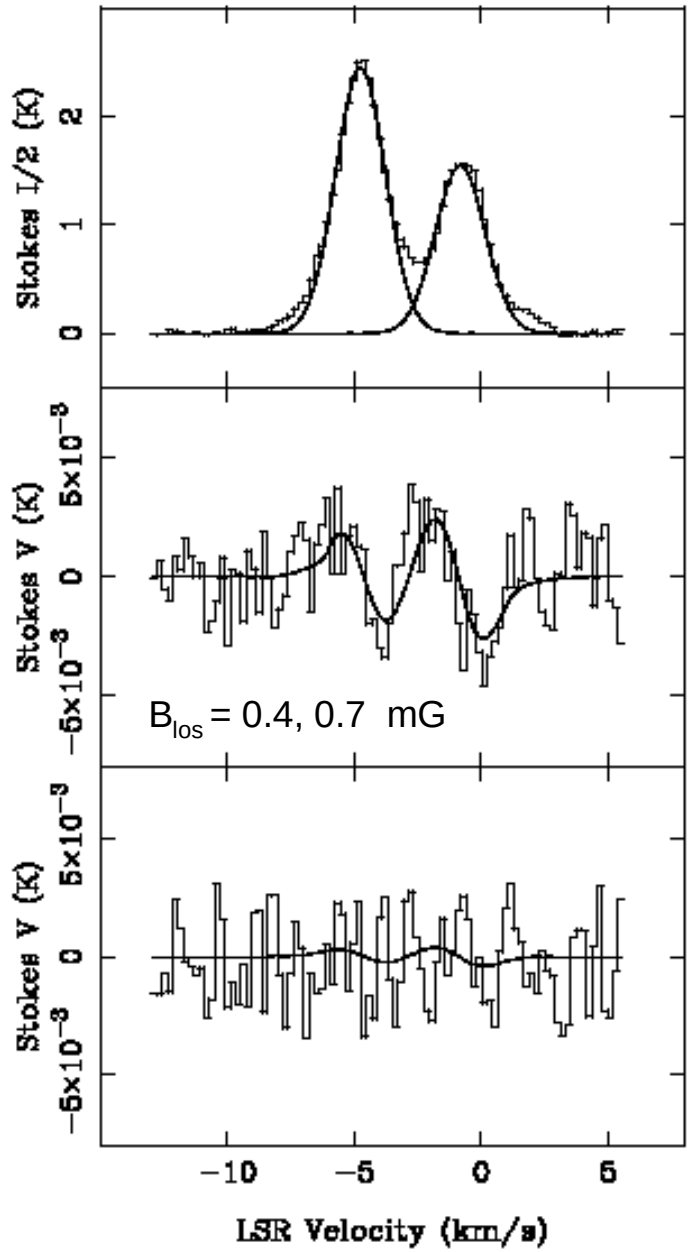
Heiles & Troland 2005

L1448 (OH Zeeman)



Troland & Crutcher 2007

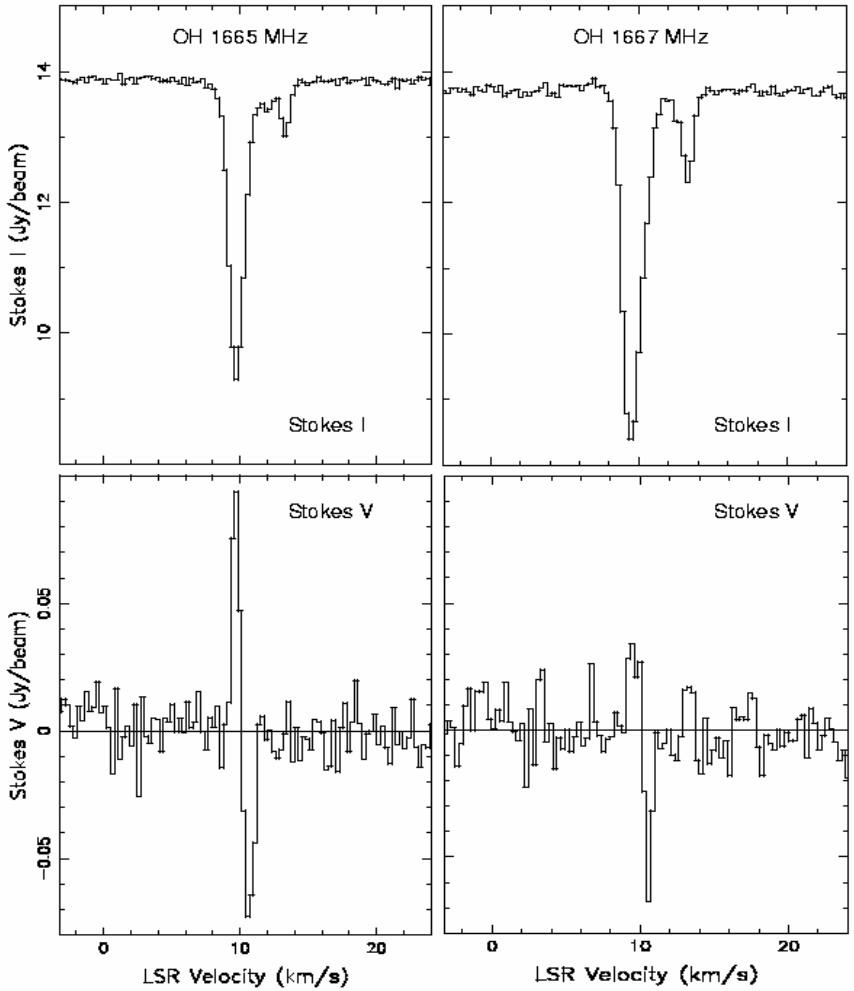
DR21OH (CN Zeeman)

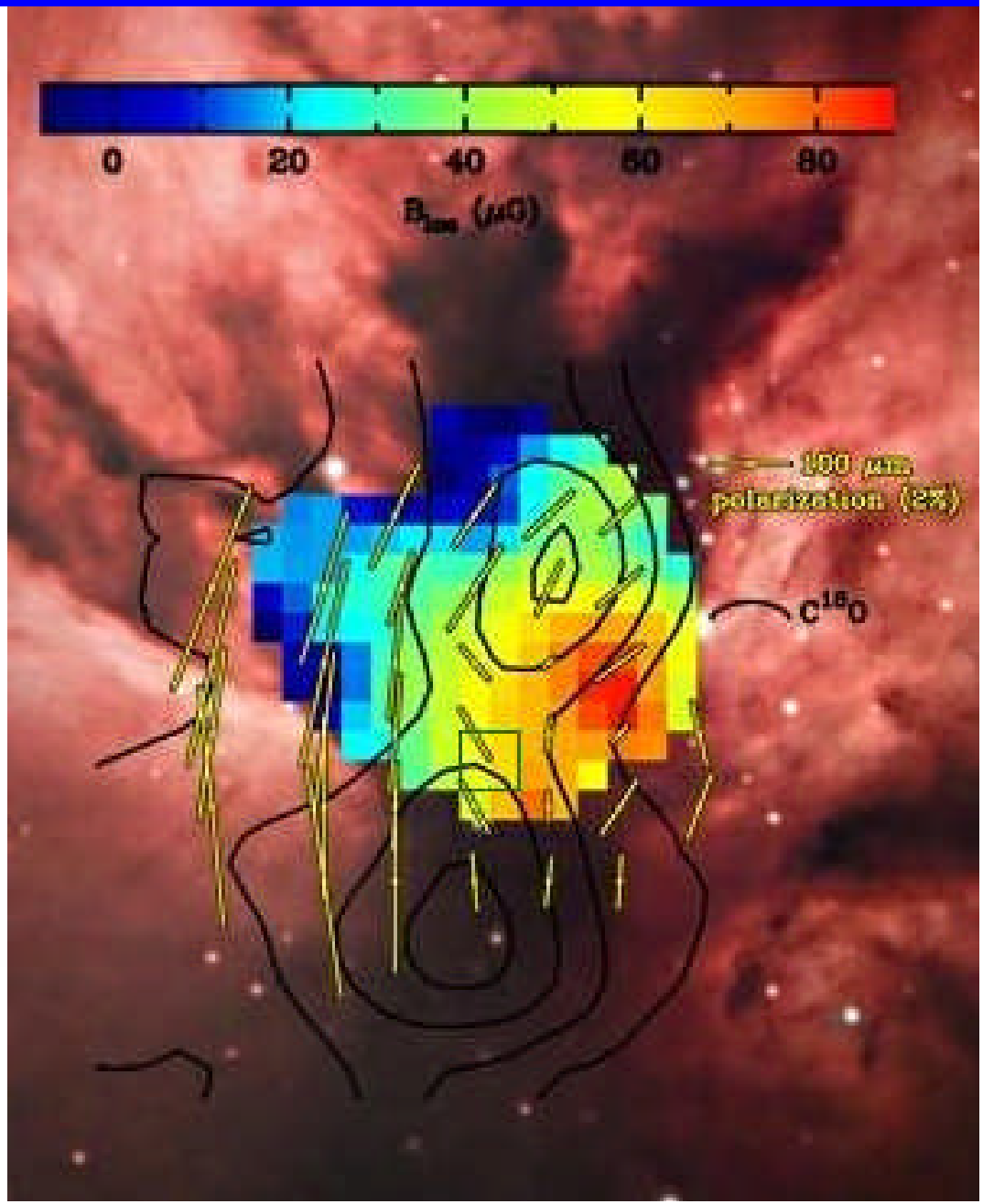


B_{los} = 0.4, 0.7 mG

Crutcher et al. 1999

NGC 2024 (Orion B) Magnetic Field Maps



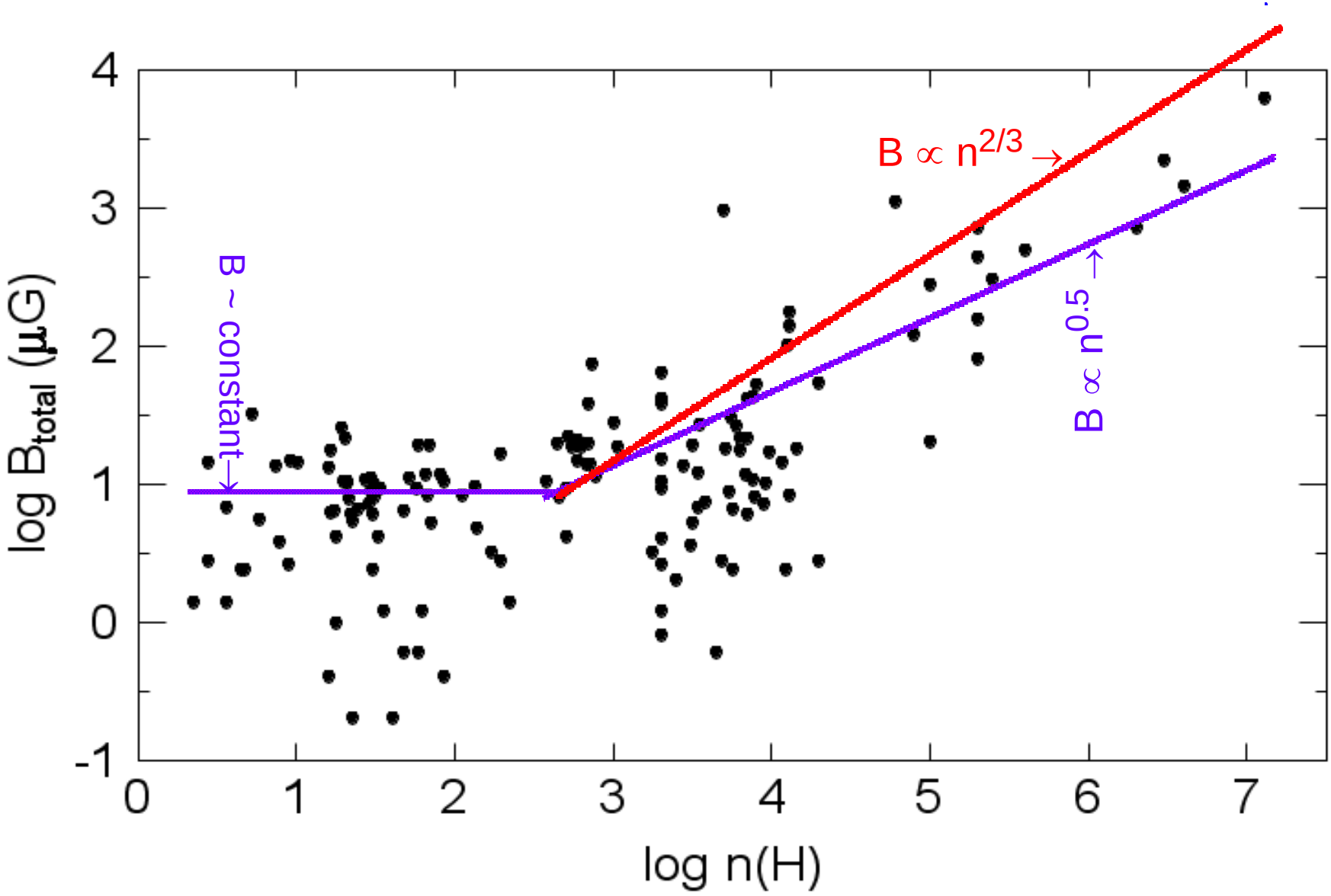


Crutcher et al. 1999

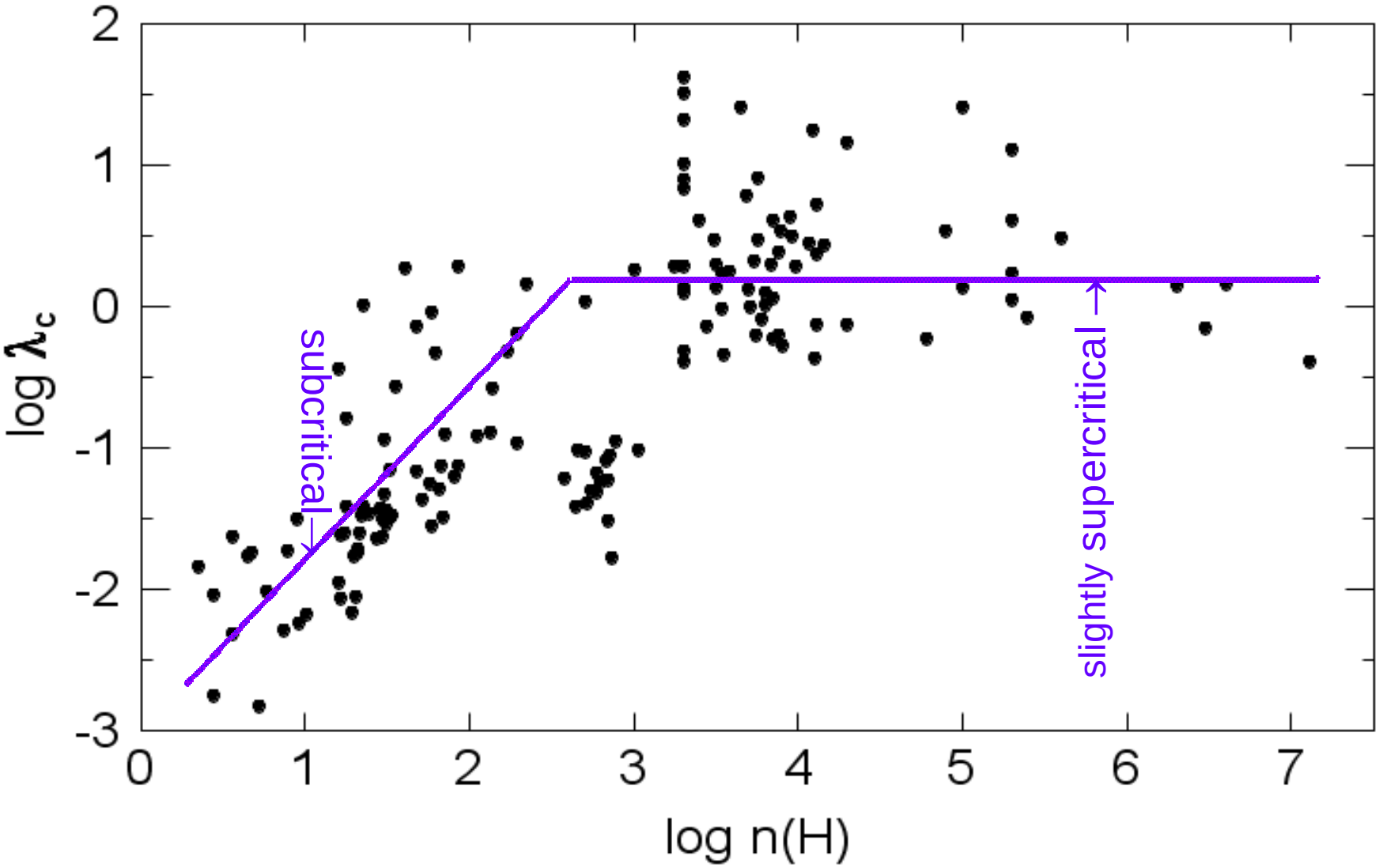
Zeeman Effect Results

Species	ν (GHz)	n(protons/cm^{-3})	B
H I	1.4	10^{1-2}	3-10 μG
OH (~thermal)	1.6	10^{3-4}	10-100 μG
CN	113.5	10^{5-6}	0.3-1 mG
OH (masers)	1.6, 6.0, 13.4	10^{7-8}	1-10 mG
H_2O (masers)	22.2	10^{9-10}	10-100 mG

Results for Field Strength

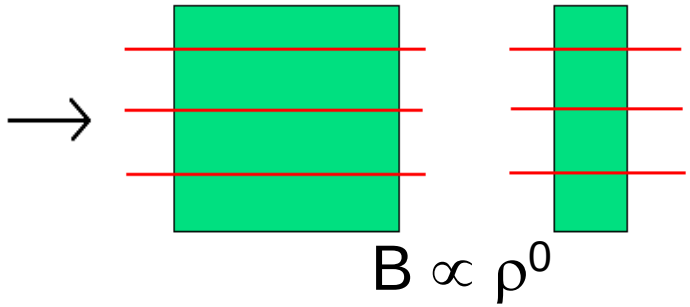


Results for Mass/Flux



Summary and Conclusions

- B invariant (B ≈ 5-10 μG) over 4 orders of magnitude in density ($\rho \sim 10^{-1}$ to 10^{3} cm^{-3})



1. MC formation by accumulation ***along*** field lines
   - turbulent accumulation
   - Parker instability
   - magneto-rotational instability
   - turbulence driven ambipolar diffusion

- M/Φ: subcritical before self-gravitation,
  ~ critical in molecular cloud cores

2. Consistent with ambipolar diffusion, with magnetic fields providing significant support against gravity for molecular cores

The Central Question

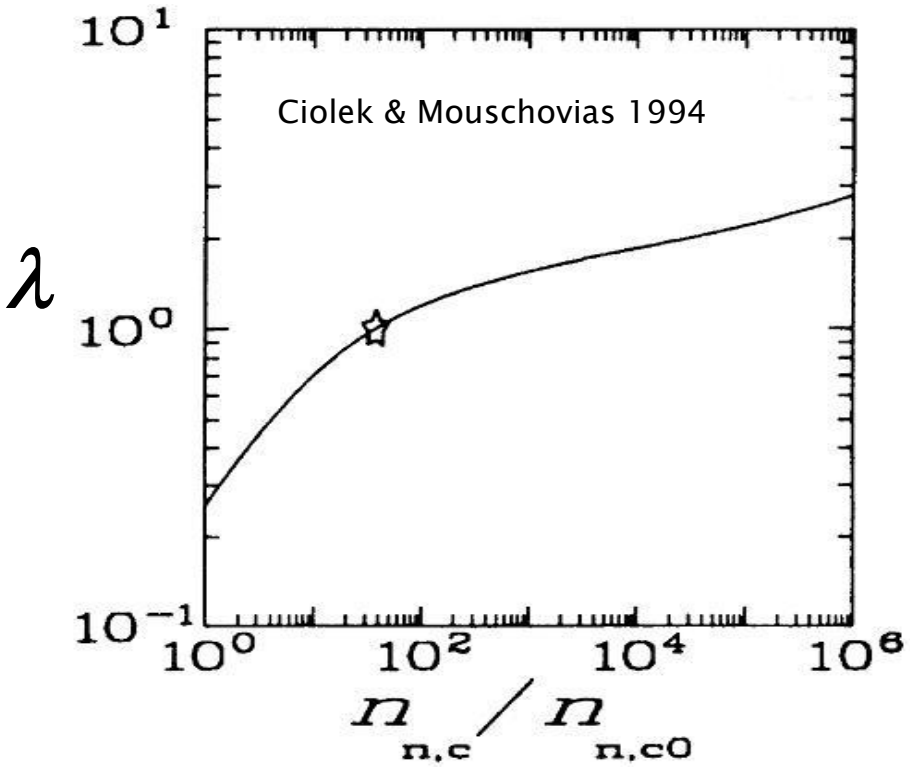
Are magnetic fields significant and/or crucial to,
or are they insignificant and a distraction from,
understanding the central physics of star formation?

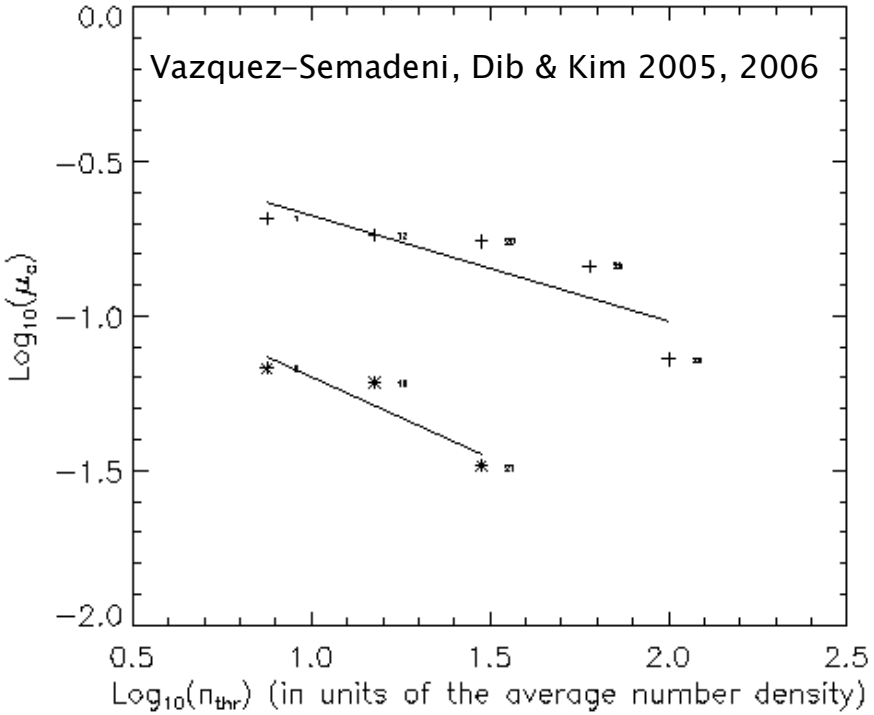
The direct answer from observations:

Magnetic fields are certainly highly significant and probably crucial to understanding the central physics of star formation!

The Future

Testing ambipolar diffusion driven core formation & star formation

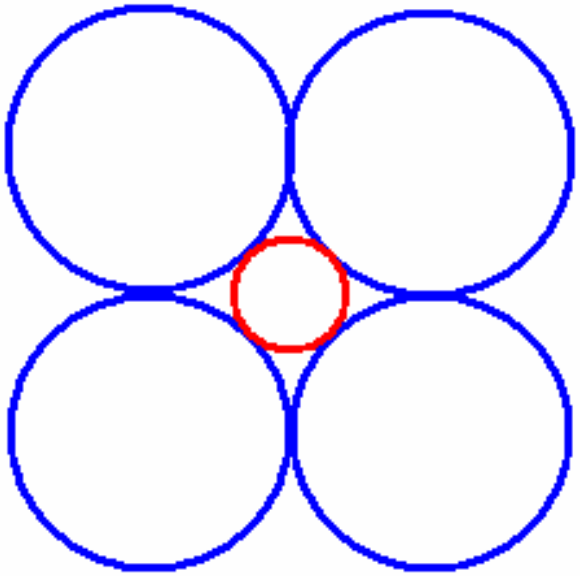


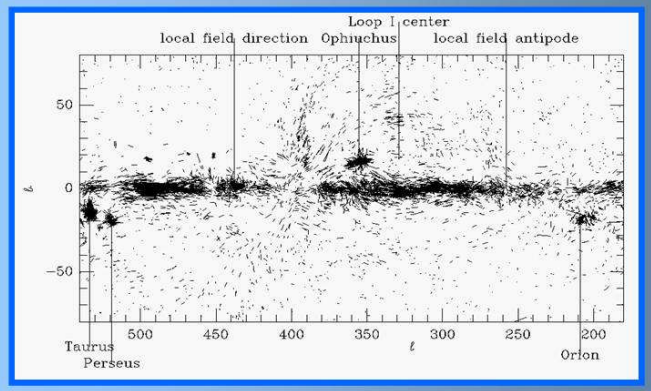


The Future

Measure differential M/Φ between core and envelope:

$$\frac{[M/\Phi]_{core}}{[M/\Phi]_{envelope}} = \frac{[T_{line}\,\Delta V / B_{los}]_{core}}{[T_{line}\,\Delta V / B_{los}]_{envelope}}$$





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- Magnetic fields in H II regions and PDRs
- Magnetic fields in dense cores
- New instrumentation & methods

Organizing Committee – C. Brogan, R. Crutcher, G. Ferland, C. Heiles, A. Sarma

http://thunder.pa.uky.edu/magnetic/

Speakers

Shantanu Basu, Crystal Brogan, You-Hua Chu, Richard Crutcher, Joanna Dunkley, Miller Goss, J. L. Han, Carl Heiles, Will Henney, Roger Hildebrand, Martin Houde, Athol Kemball, Alex Lazarian, Zhi-Yun Li, Mordecai Mac Low, Antonio Mario Magalhaes, Brenda Matthews, Telemachos Mouschovias, Giles Novak, Bob O'Dell, Eve Ostriker, Rick Perley, Richard Plambeck, Ramprasad Rao, Tim Robishaw, Anish Roshi, Anuj Sarma, Lew Snyder, Tom Troland, Bill Watson, Robin Williams, Al Wootten, Ellen Zweibel (as of July 2007)