Testing Ambipolar Diffusion Driven Star Formation Theory

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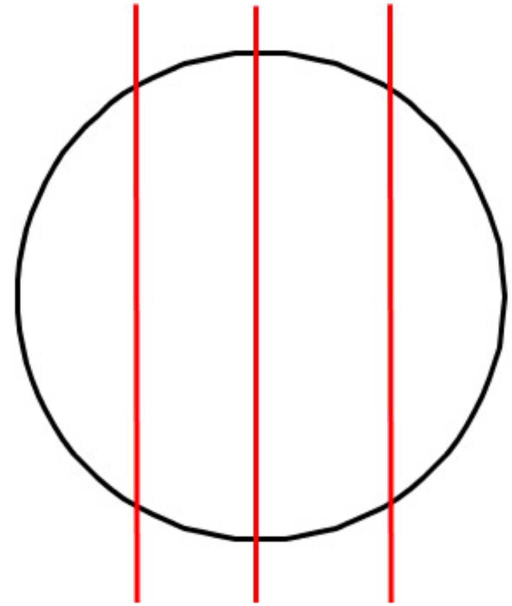
Testing Ambipolar Diffusion Driven Star Formation Theory

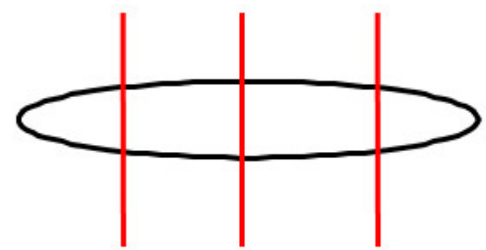
Conclusion: There is no definitive observational evidence in support of ambipolar diffusion driven star formation. Although ambipolar diffusion may drive some star formation, it does not seem to be the dominant mechanism.

Idealized Ambipolar Diffusion Models



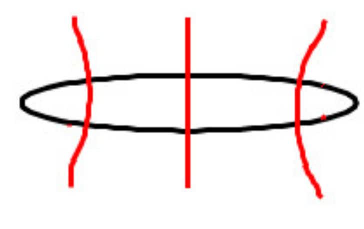
Initial Conditions

- uniform density spherical cloud & magnetic field lines
- forces are gravity, and magnetic & thermal pressure



Relaxation to Equilibrium Conditions

- matter flows along field lines until thermal pressure, gravity balance along field lines
- magnetic pressure (mainly) balances gravity perpendicular to field lines, with hourglass morphology



Ambipolar Diffusion

- neutrals collapse through field toward center, dragging ions and field lines inward – hourglass morphology field becomes more pronounced

Measureable Parameters

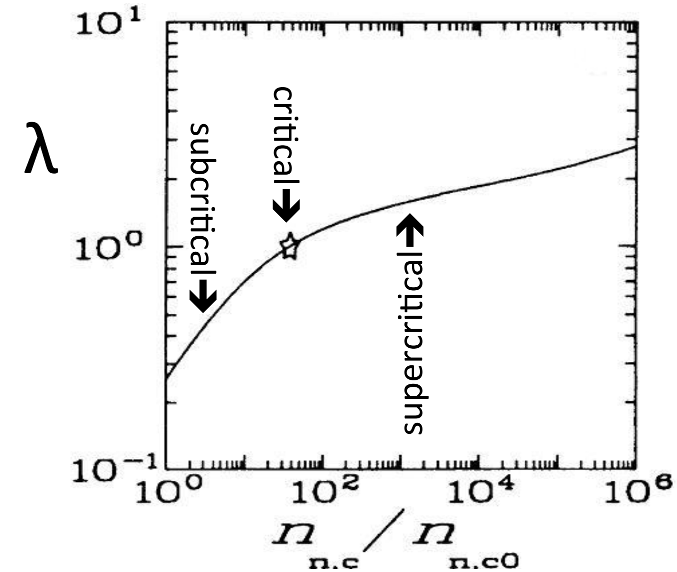
1) M/Φ: ratio of gravity to magnetic fields

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

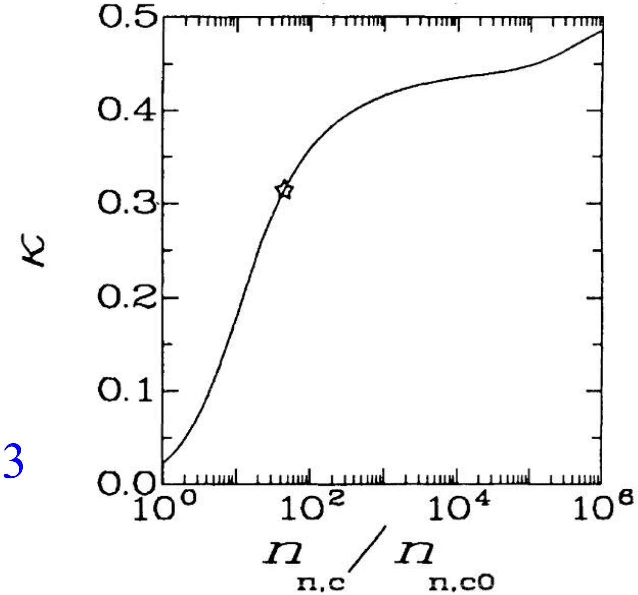
Nakano & Nakamura 1978

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

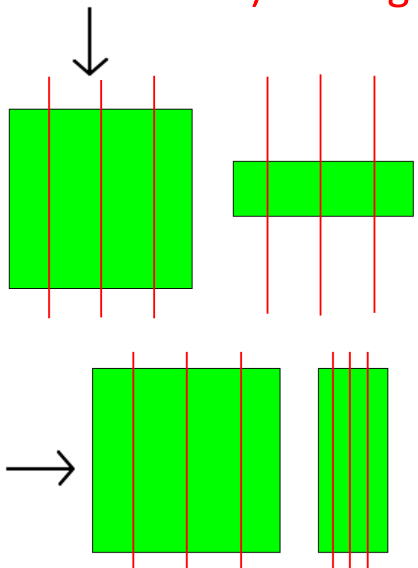
$$\lambda \equiv \frac{(M/\Phi)_{observed}}{(M/\Phi)_{critical}}$$



Ciolek & Mouschovias 1994

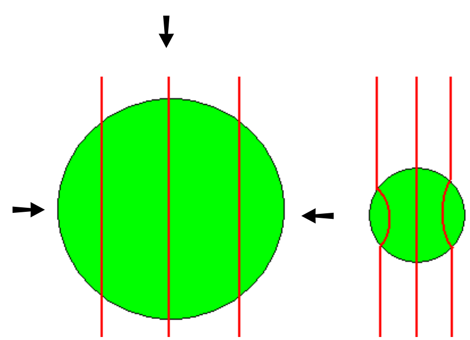


2) Scaling of B: $B \propto \rho^{\kappa}$



$$B \propto \rho^0$$

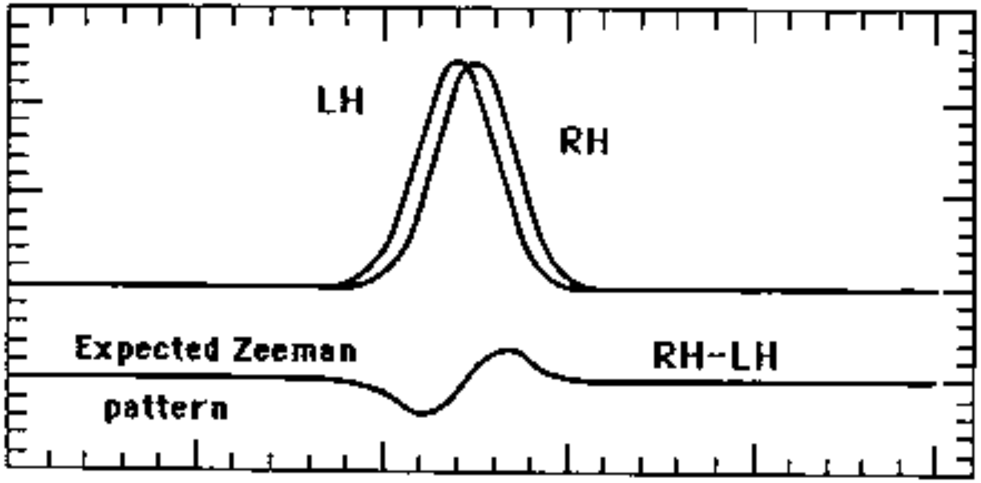
$$B \propto \rho^1$$



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

Mestel 1966

Zeeman Effect

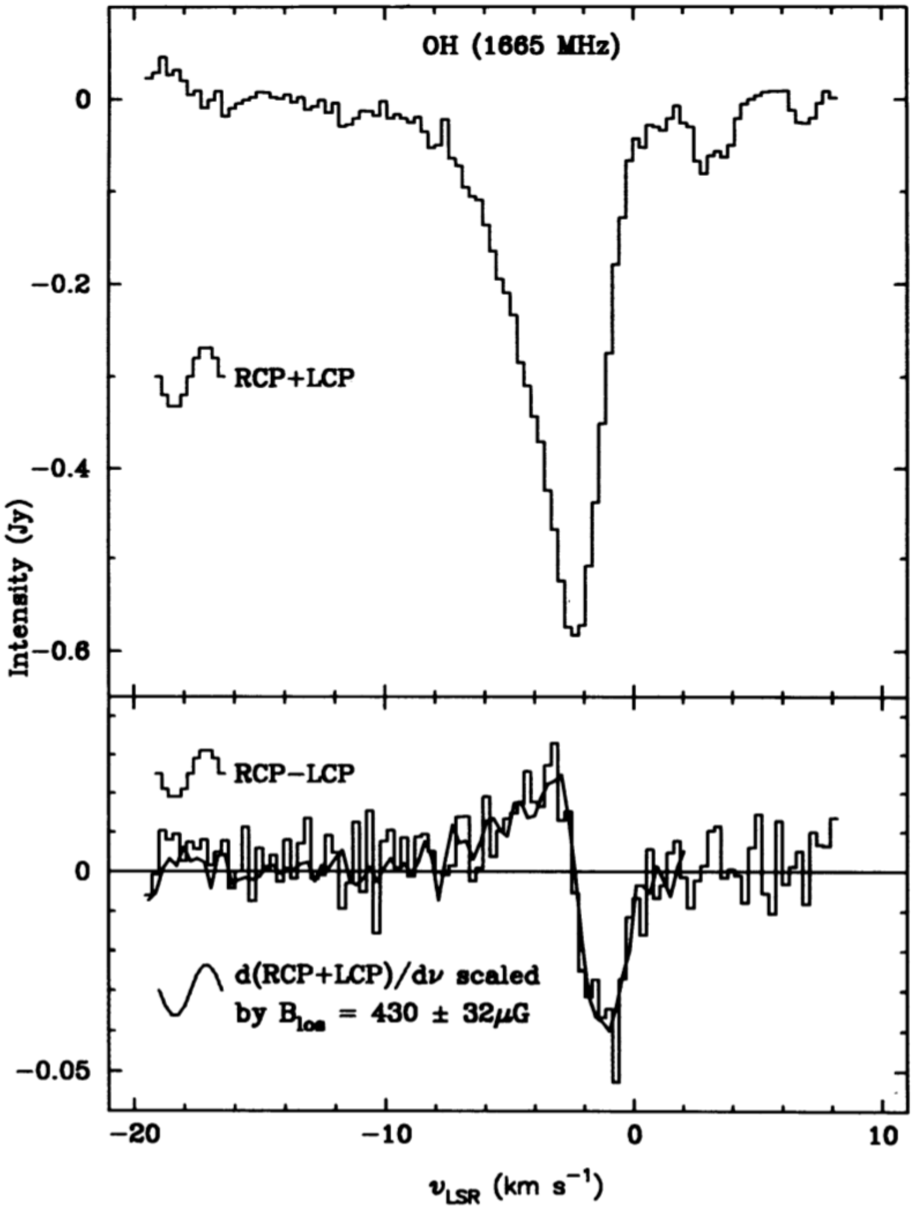


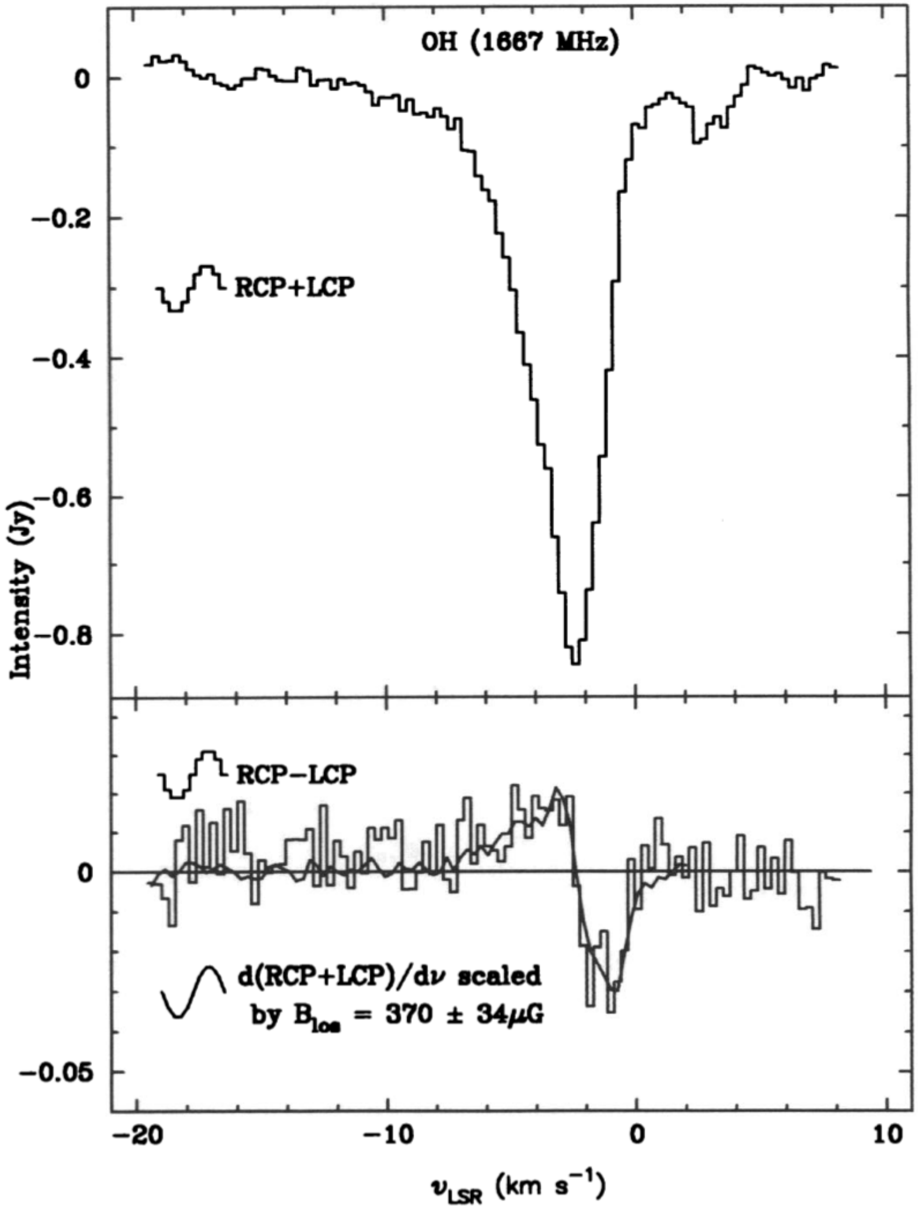
Pieter Zeeman
(1865 – 1943)

$$V = R - L \propto (dI/d\nu)(Z\,B\,cos\theta) \Rightarrow B_{LOS}$$

Species	Wavelength	n(H) traced
H I	21-cm	$10^{1} - 10^{2}$ cm^{-3}
OH	18-cm	$10^{3} - 10^{4}$ cm^{-3}
CN	3 mm	$10^{5} - 10^{6}$ cm^{-3}

Zeeman Effect Example – S106



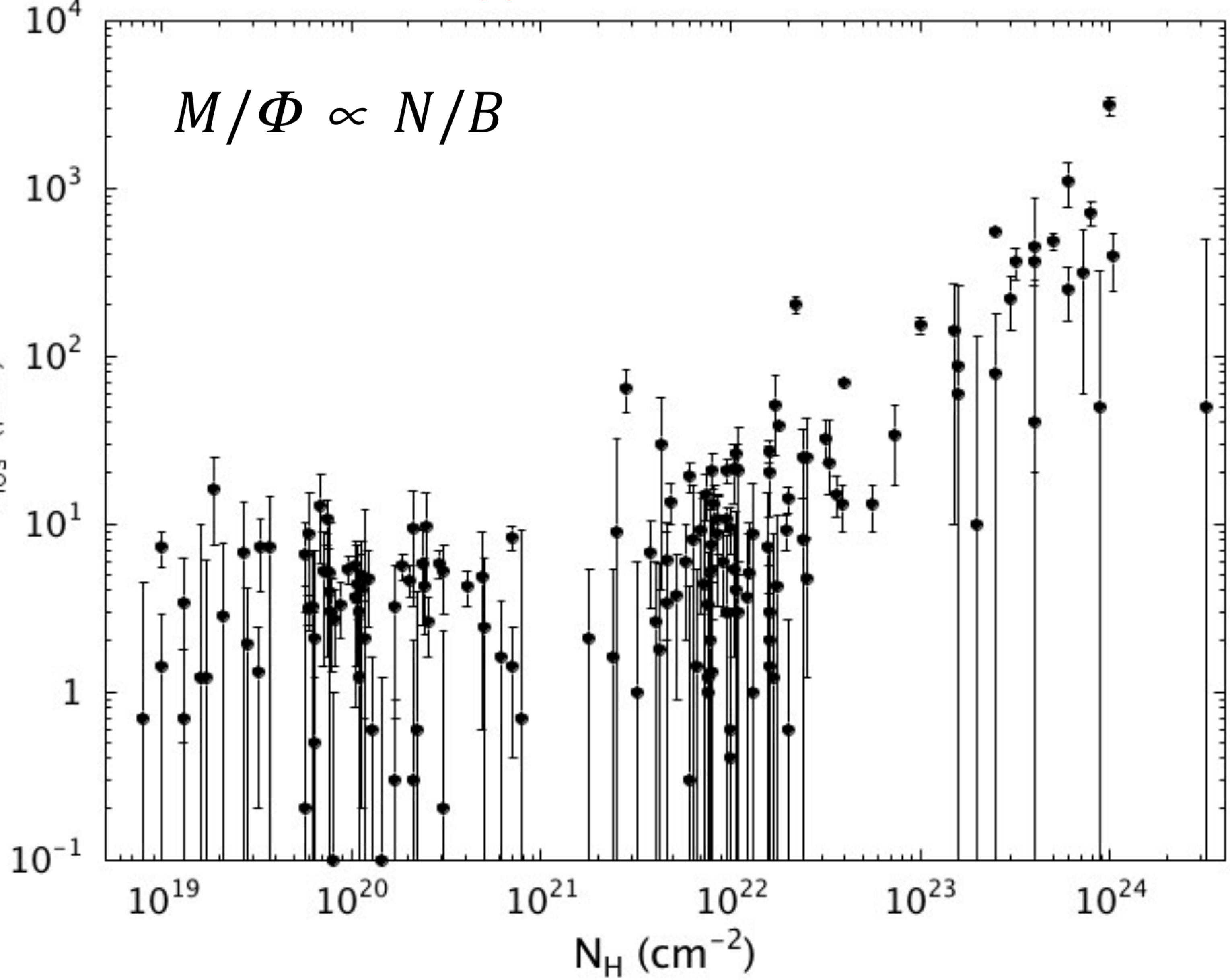


Roberts, Crutcher & Troland 1995

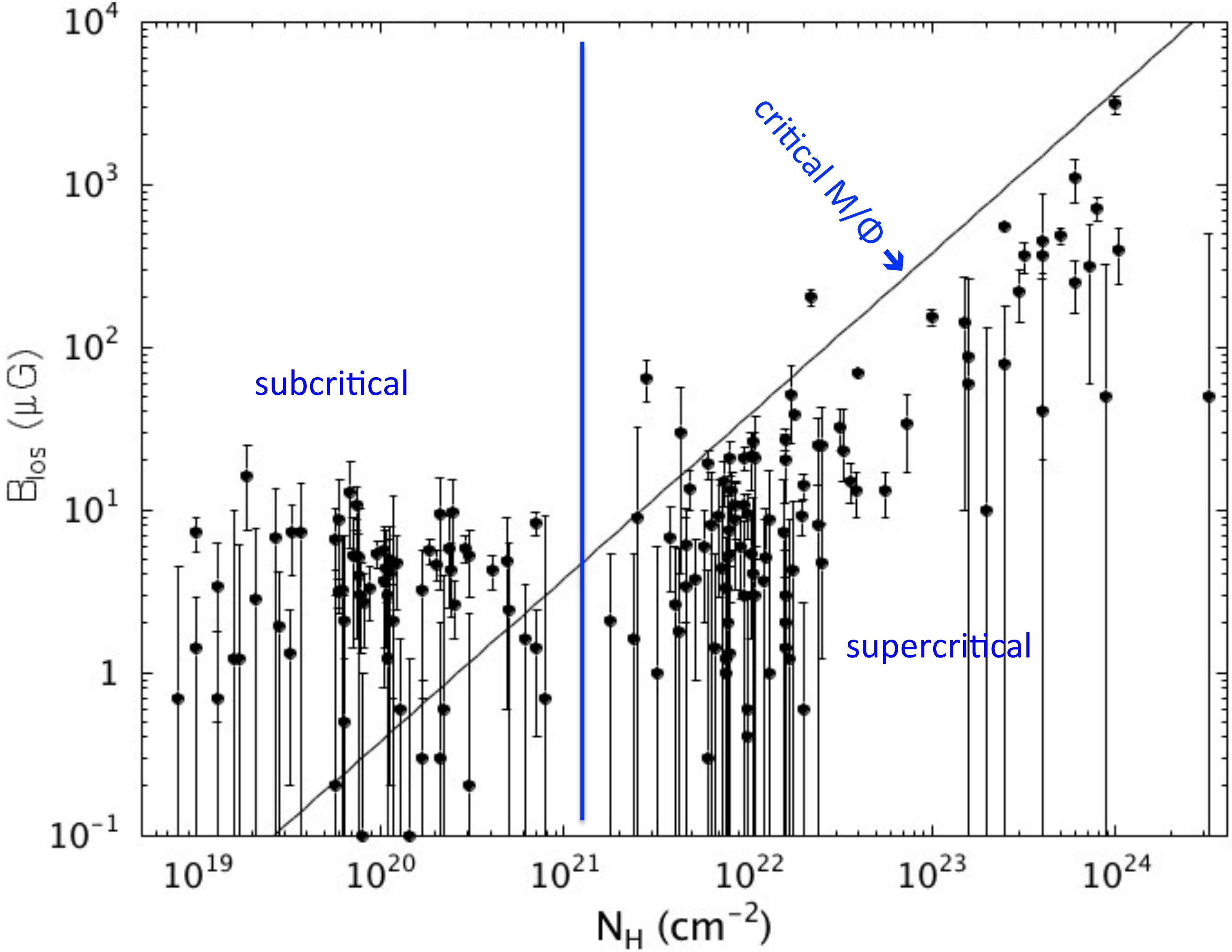
Major Zeeman Surveys

Data Set	Measurements of B_{los}
1. Compilation Crutcher 1999	27
2. OH absorption-lines Bourke, Myers, Robinson & Hyland 2001	22
3. Arecibo H I Millennium survey Heiles & Troland 2004, 2005	67
4. Arecibo OH dark clouds Troland & Crutcher 2008	34
5. IRAM 30-m CN Falgarone, Troland, Crutcher, & Paubert 2008	11 (+3 included in #1)
TOTAL	161

B_{LOS} versus N



B_{LOS} versus N



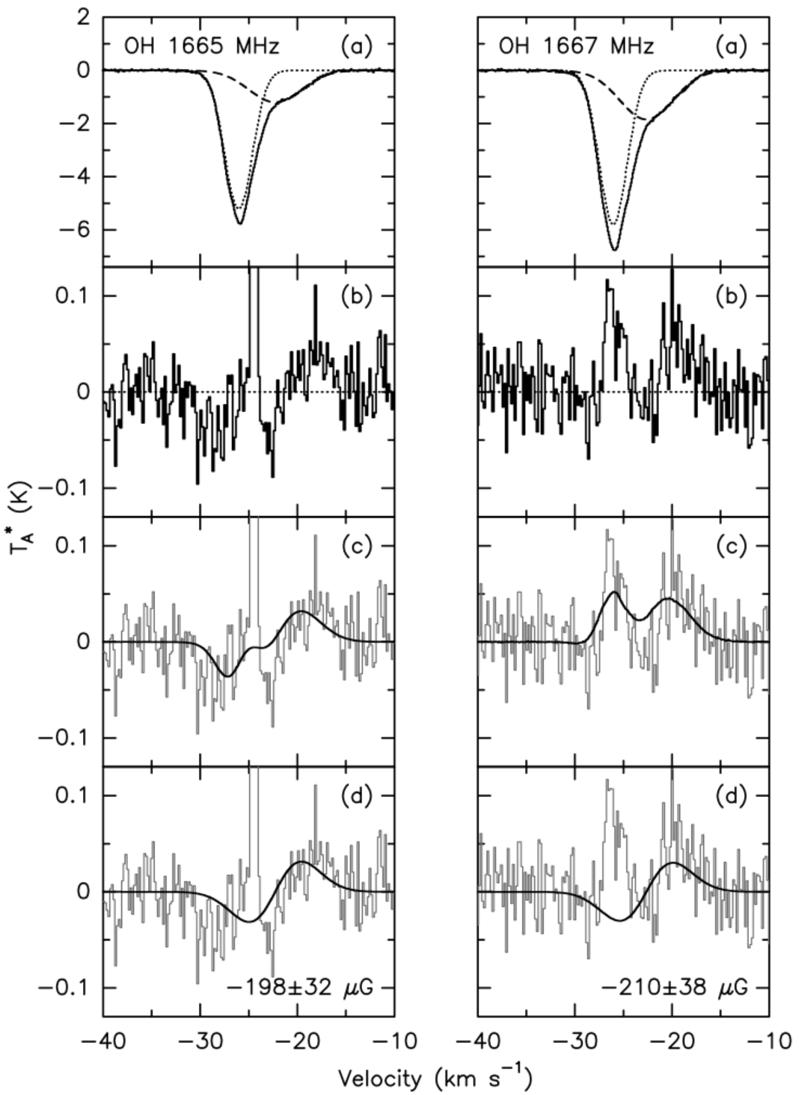
B_{LOS} versus N

G14.0-0.6

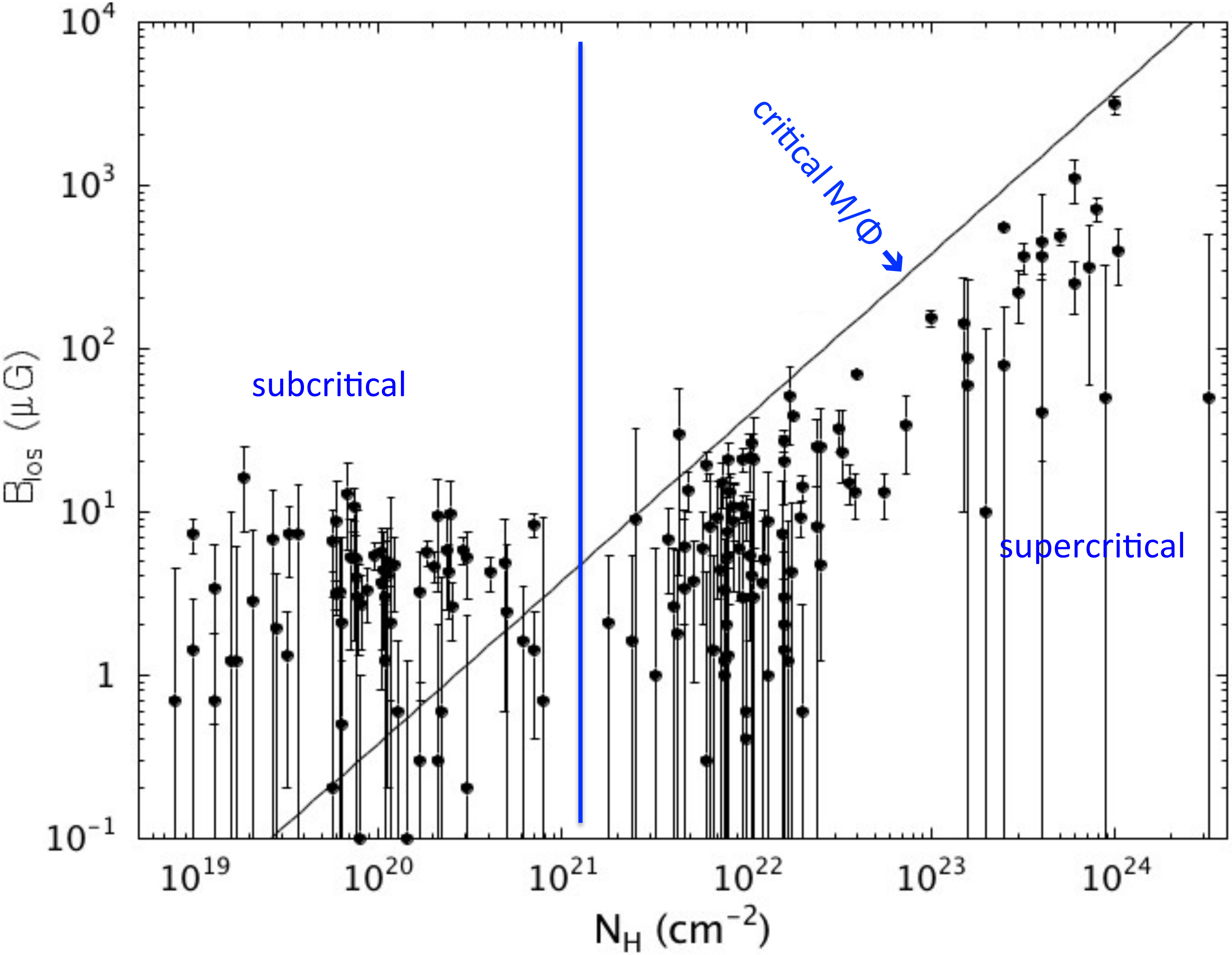
B(1667) = +135 ± 27 μG

B(1665) = -1 ± 26 μG

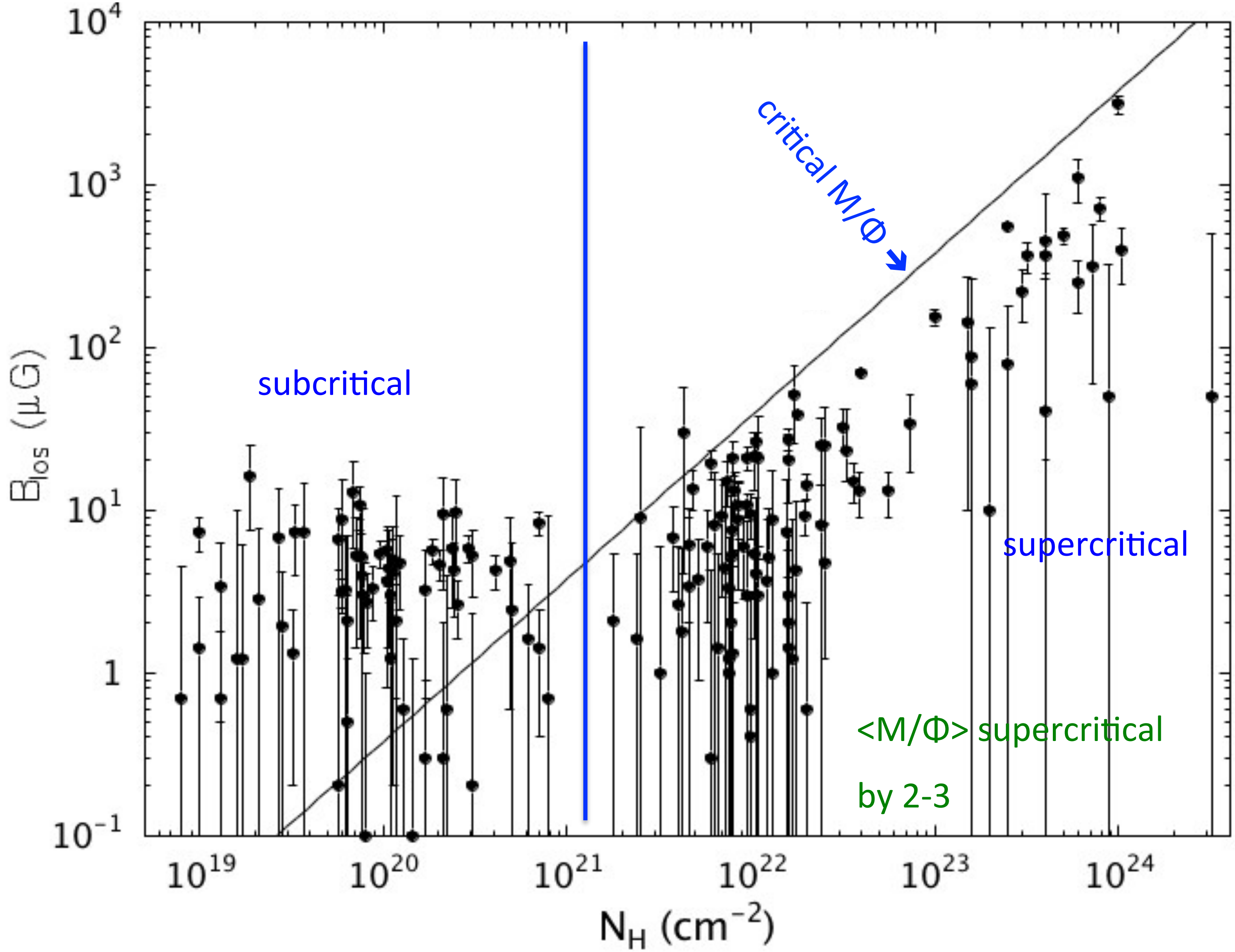
RCW 57



B_{LOS} versus N_H

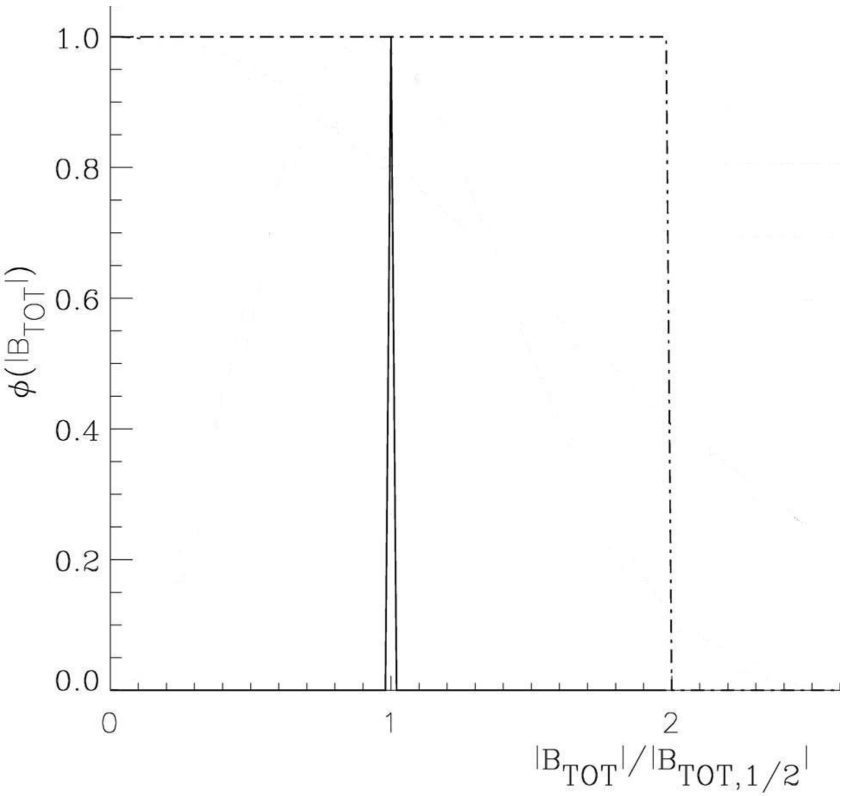


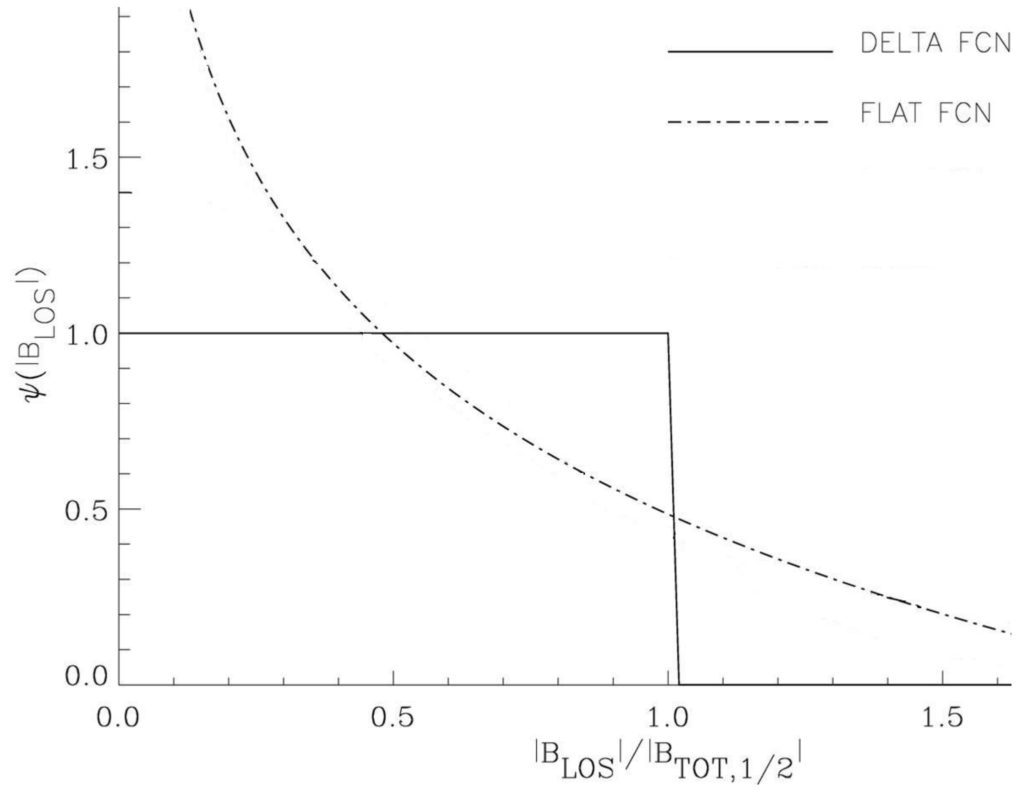
B_{LOS} versus N_H



What to do about measuring B_{los}, not B_{tot}?

PDFs of total B and corresponding los B

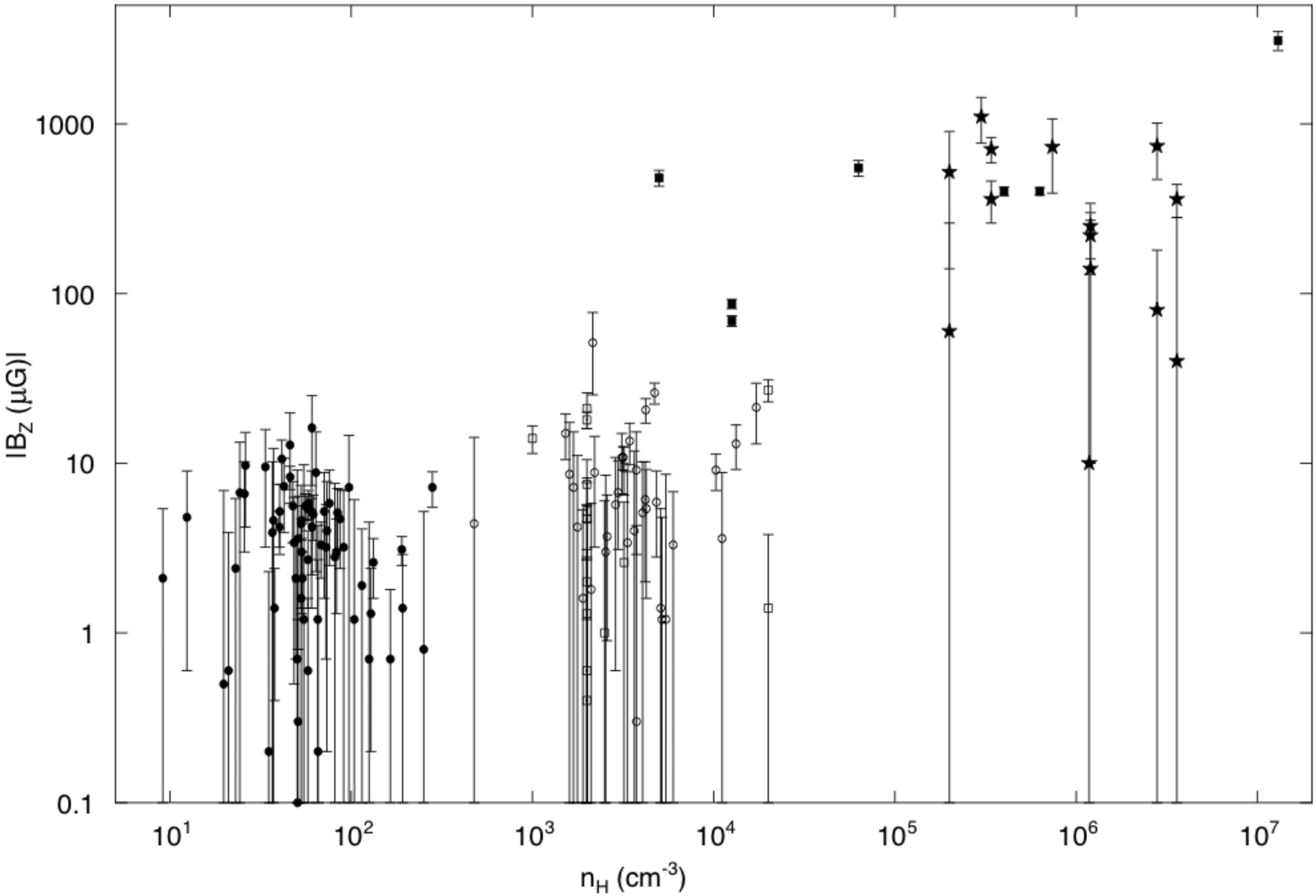




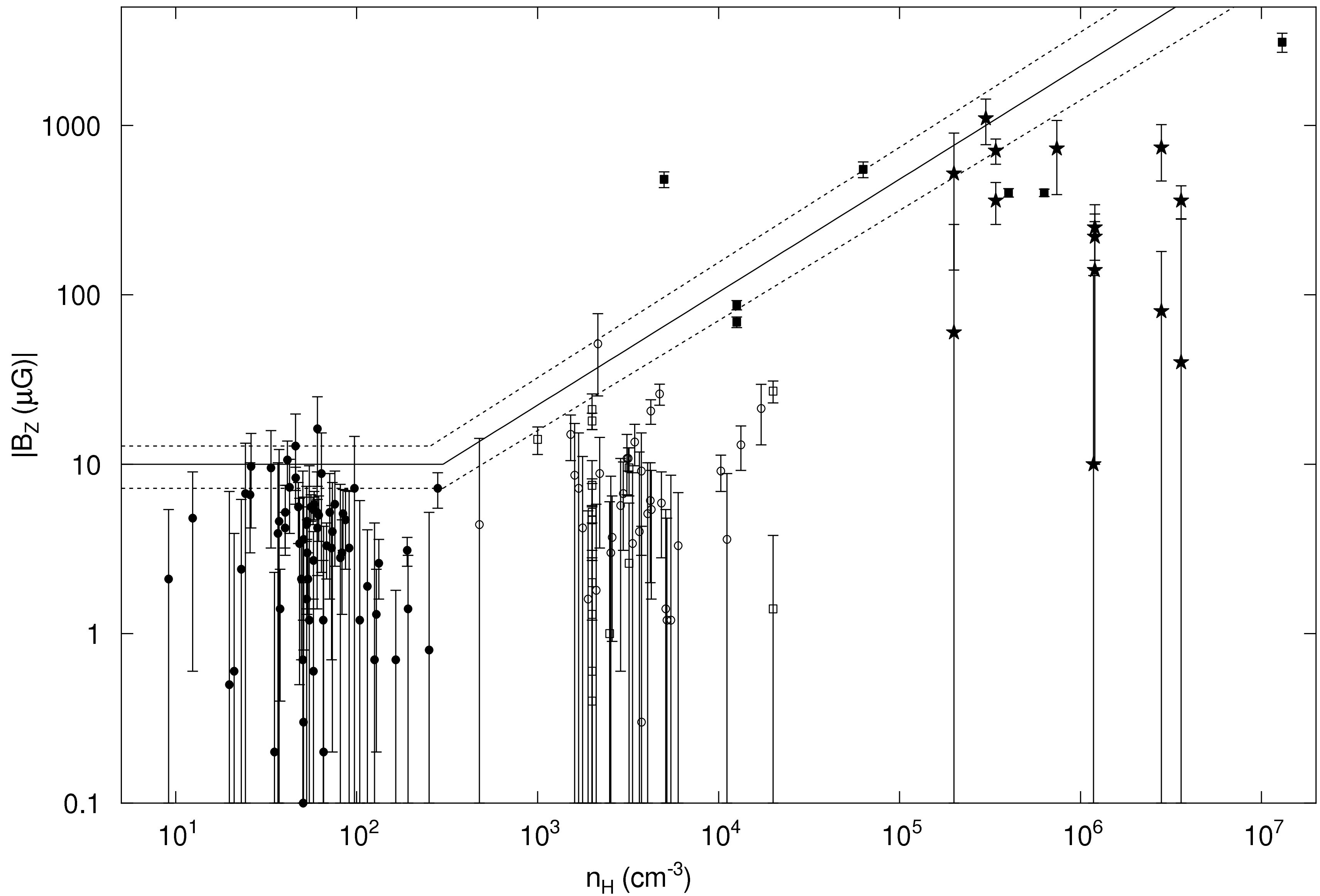
For reasonable pdf, mean or median of B_{los} ≈ ½ mean or median of B_{total}

Heiles & Crutcher 2005

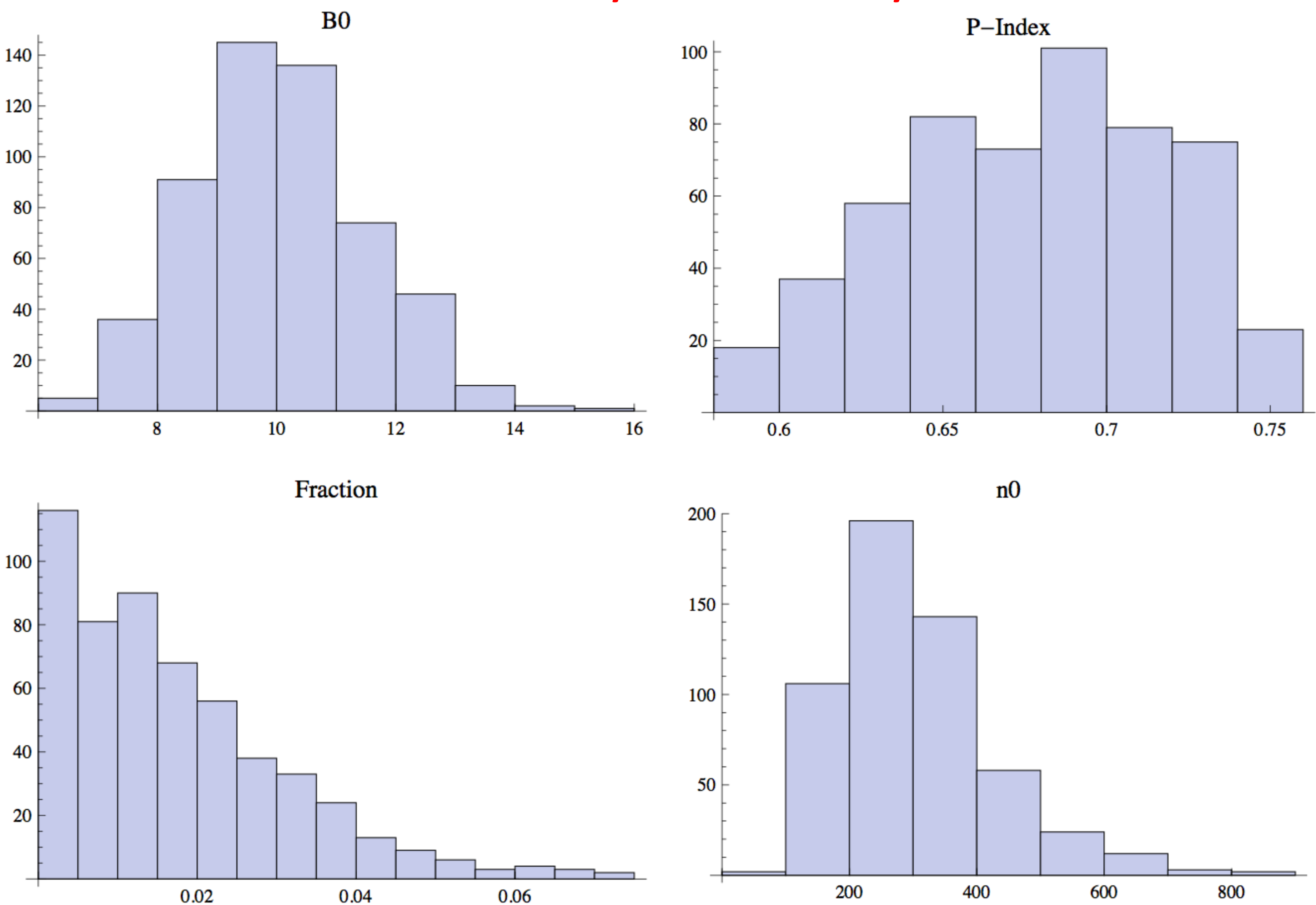
B_{LOS} versus n_H



Results for B_{TOT} versus n_H



Results of Bayesian Analysis

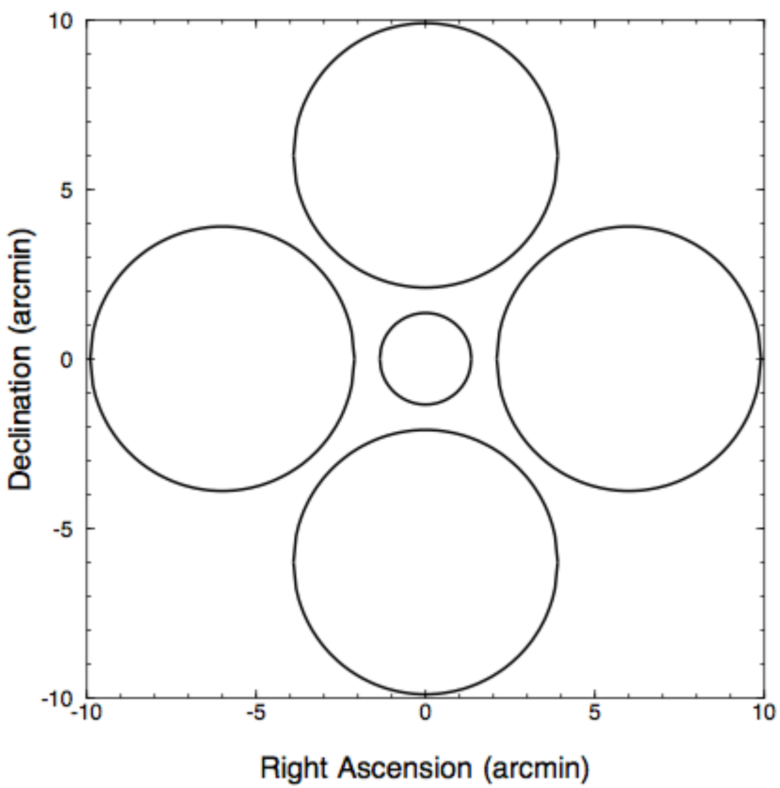


Crutcher et al. 2010

Testing M/Φ Change from Envelope to Core

Measure differential M/Φ between core and envelope:

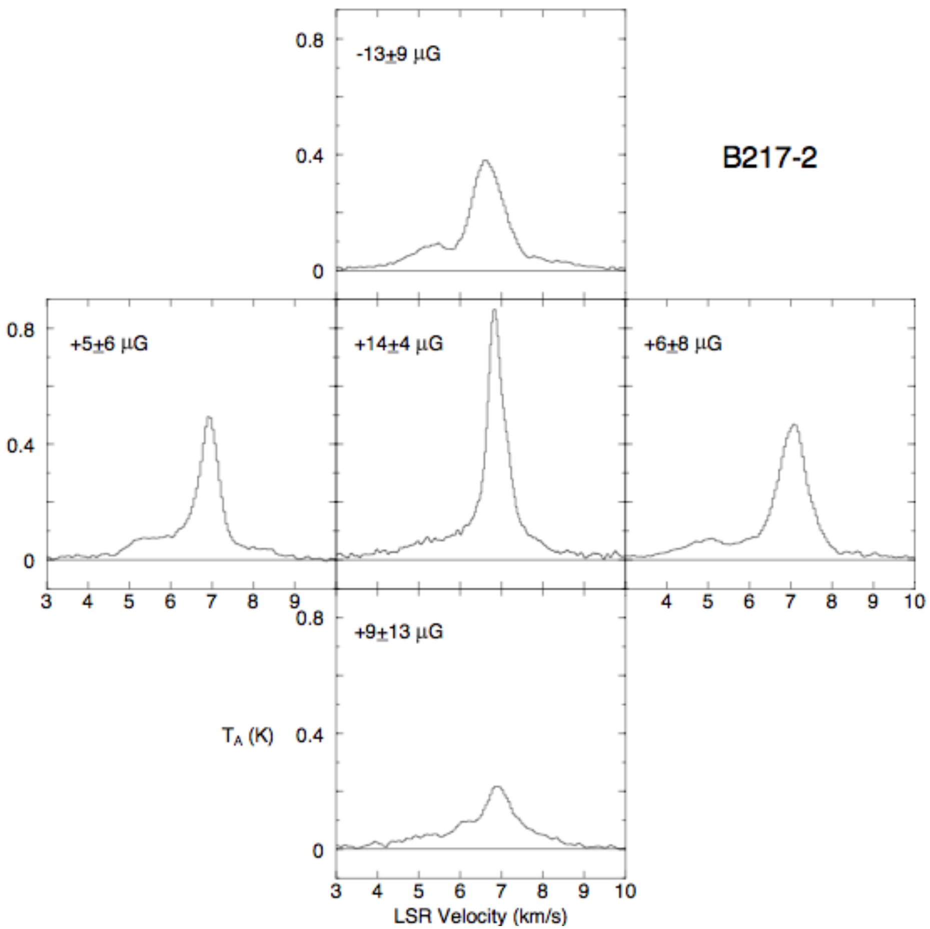
$$\frac{[M/\Phi]_{core}}{[M/\Phi]_{envelope}} = \frac{[T_{line}\,\Delta V / B_{los}]_{core}}{[T_{line}\,\Delta V / B_{los}]_{envelope}}$$

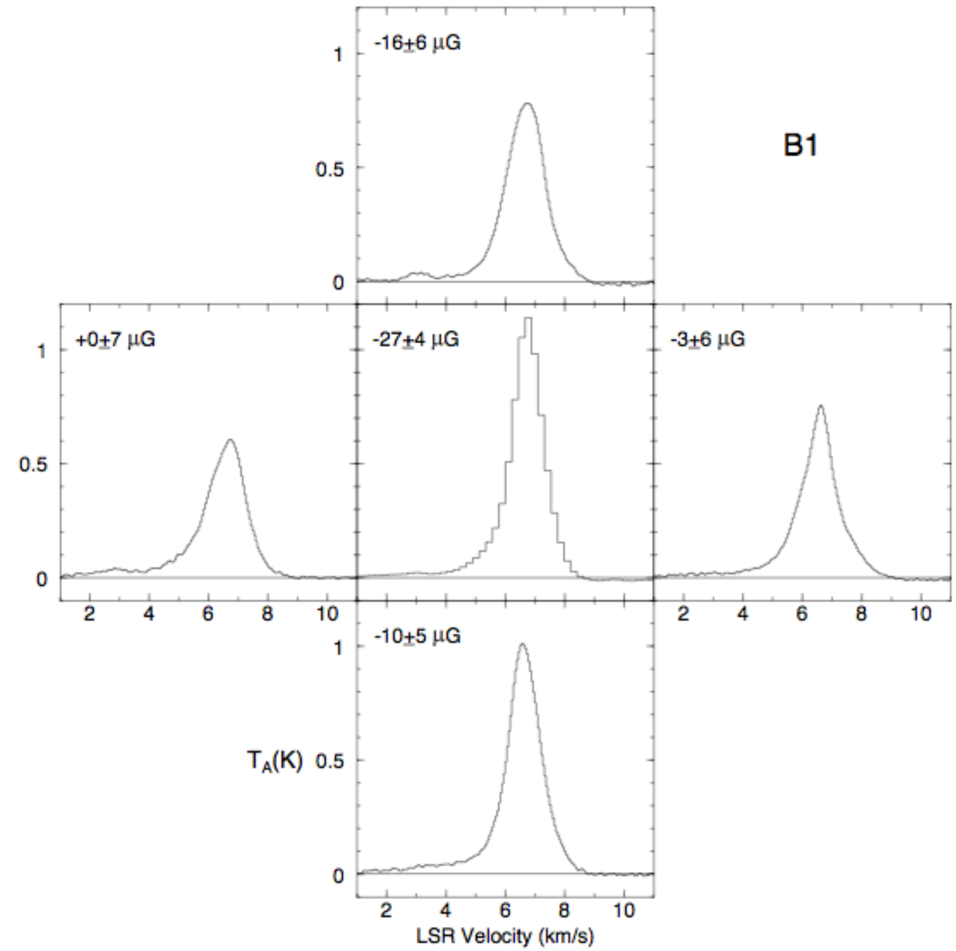


Telescope beam sizes were chosen to ideally sample core and envelope regions of published ambipolar diffusion models. Averaging the four large GBT beams "synthesizes" a toroidal beam, exactly what is needed to sample only the envelope region.

Crutcher, Hakobian, & Troland 2008

Testing M/Φ Change from Envelope to Core





Results

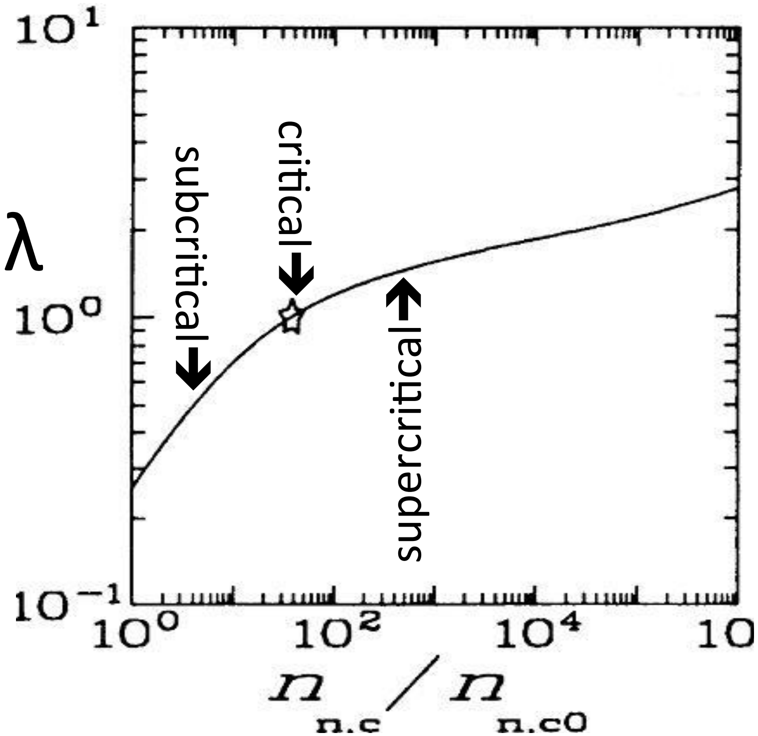
Cloud:	L1448	B217-2	L1544	B1
B(core):	-26 ± 4	+14 ± 4	+11 ± 2	-27 ± 4
B(envelope):	-3 ± 4	+2 ± 5	+5 ± 3	-7 ± 4
$T_{line}\,\Delta V$ (core):	1.21	0.60	1.17	2.20
$T_{line}\,\Delta V$(envelope):	0.73	0.47	0.64	1.60
$\frac{M/\Phi\text{ (core)}}{M/\Phi\text{ (envelope)}}$:	0.21 ± 0.30	0.19 ± 0.46	0.89 ± 0.59	0.37 ± 0.18
Difference from 1:	2.6 σ	1.7 σ	0.2 σ	3.5 σ

Published ambipolar diffusion models require ratio ~ $1/\lambda_{initial}$, typically ~ 2

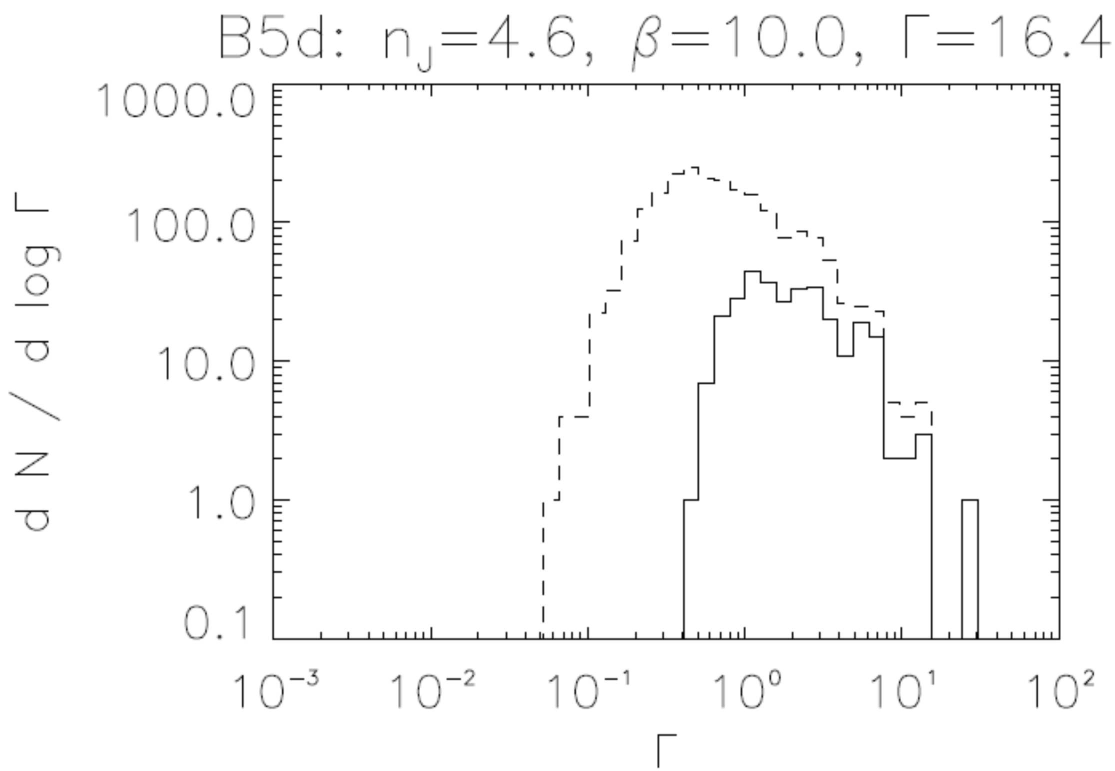
Crutcher, Hakobian, & Troland 2008

Predictions for M/Φ

ambipolar diffusion



turbulence



Ciolek & Mouschovias 1994

Tilley & Pudritz 2007

Models for Specific Clouds

1. Take observed properties (mass, radius, B_{LOS})
2. Assume initial cloud properties (mass, radius, M/Φ)
3. Evolve model and compare with observations

B 1

Crutcher, Mouschovias, Troland & Ciolek (1994)

	Theory	Observed
$1/\lambda$	2.4	0.37 ± 0.18
B_{LOS}(μG)	85 $\cos 70°$ = 29	27

L 1544

Ciolek & Basu (2000)

	Theory	Observed
$1/\lambda$	1.25	0.89 ± 0.59
B_{LOS}(μG)	40 $\cos 74°$ = 11	11

Summary

1. No subcritical self-gravitating clouds are observed
2. $\langle M/\Phi \rangle$ for molecular clouds is supercritical by 2-3
3. No observed M/Φ for molecular clouds is subcritical
4. PDF of B_{TOTAL} is flat $\Rightarrow$ many self-gravitating, supercritical clouds
5. Power law in $B \propto \rho^{\kappa}$ relationship is $\kappa \approx 2/3$, implying that contraction is roughly isotropic, i.e., not dominated by magnetic fields
6. Core/envelope $M/\Phi < 1$ in 4 dark clouds, not > 1 as ambipolar diffusion requires
7. Ambipolar diffusion models of B 1 and L 1544 give observed parameters, but require that B be nearly in the plane of the sky; B_{TOTAL} are significantly larger than any B_{LOS} ever observed

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5. Power law in $B \propto \rho^{\kappa}$ relationship is $\kappa \approx 2/3$, implying that contraction is roughly isotropic, i.e., not dominated by magnetic fields
6. $(M/\Phi)_{core}/(M/\Phi)_{envelope} < 1$ in 4 dark clouds, not > 1 as ambipolar diffusion requires
7. Ambipolar diffusion models of B 1 and L 1544 give observed parameters, but require that B be nearly in the plane of the sky; B_{TOTAL} are significantly larger than any B_{LOS} ever observed

Conclusion

There is no definitive observational evidence in support of ambipolar diffusion driven star formation. Although ambipolar diffusion may drive some star formation, it does not seem to be the dominant mechanism.