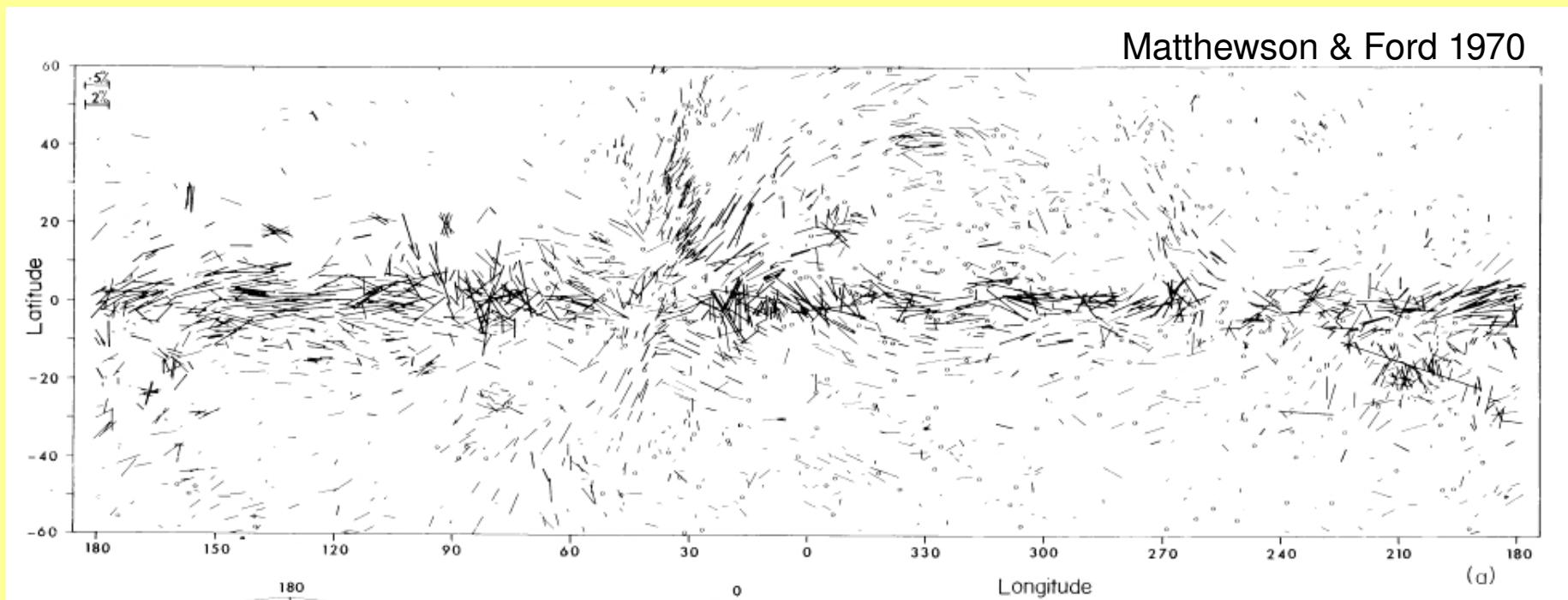


# Magnetic Fields: Early History (pre-1995)

Mark Heyer  
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# Outline

- Physical Motivation and Expectations
- Observations
  - Magnetic Field geometry
    - Polarization of background stars
    - Polarization of dust emission
  - Magnetic Field Strength
    - Zeeman Measurements
- Where we stood in 1995

# Theoretical Motivation

What supports the cloud against self-gravitational collapse for many free-fall times?

Mestel & Spitzer (1956)

Mouschovias & Spitzer (1976)

Nakano (1978)

Lizano & Shu 1988

$$\begin{aligned} M_{\text{crit}} &= (1/63G)^{1/2} \Phi \\ &= 10^3 M_{\text{sun}} (B/30 \mu G) (R/2 \text{ pc})^2 \\ \Sigma_{\text{crit}} &= 80 M_{\text{sun}}/\text{pc}^2 (B/30 \mu G) \end{aligned}$$

# Theoretical Motivation

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Ambipolar Diffusion allows a small fraction of a subcritical cloud to become supercritical (dense cores) and form stars

# Theoretical Motivation

What processes resolve the magnetic flux and angular momentum problems of star formation?

$$R_{\text{cloud}}/R_{\text{star}} \sim 10^8$$

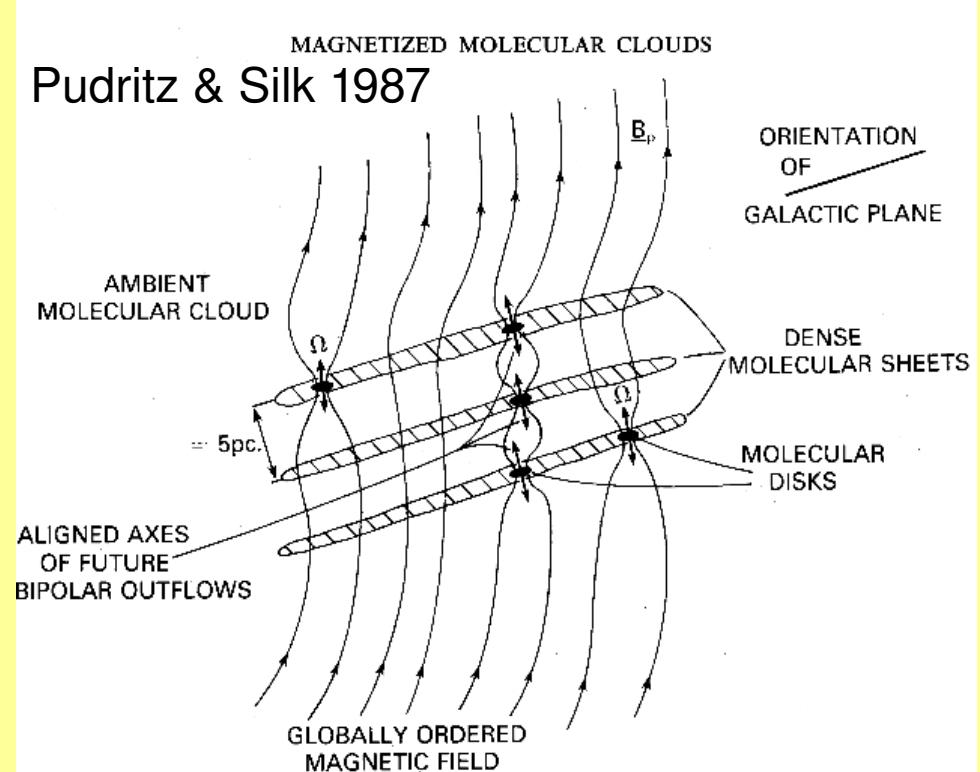
Gillis, Mestel, Paris, 1974, 1979

Fleck & Hunter 1976

Mouschovias 1977, 1979, 1985, 1991

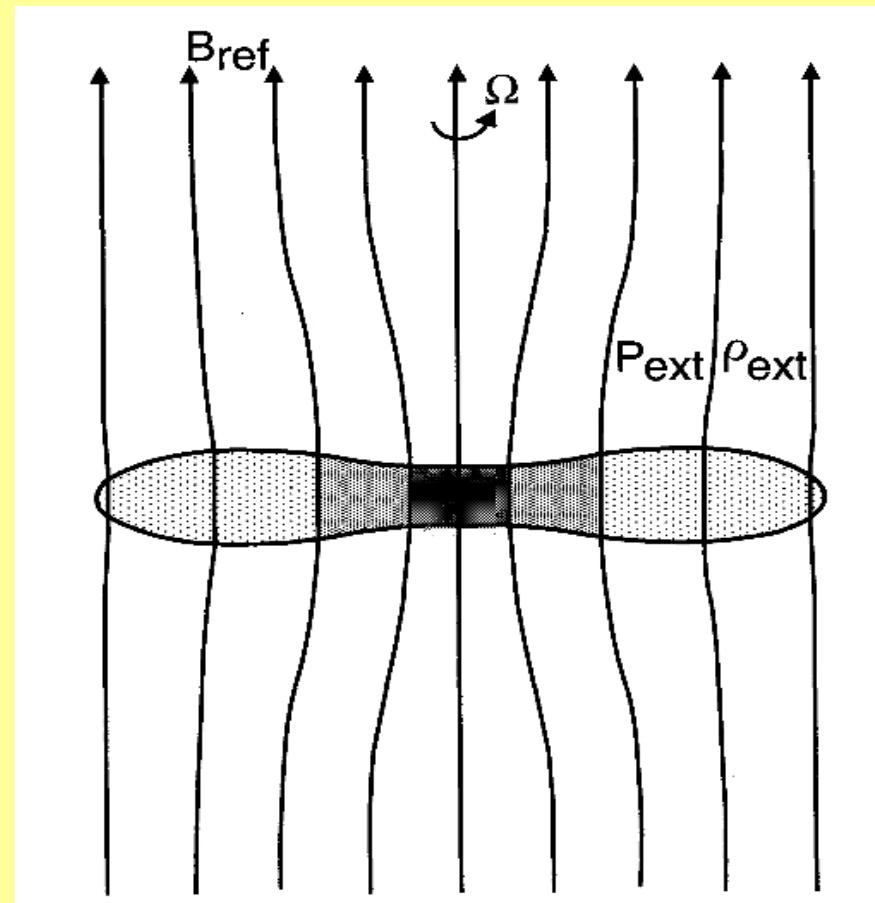
Mouschovias & Paleologou 1982

Basu 1993



# Expectations

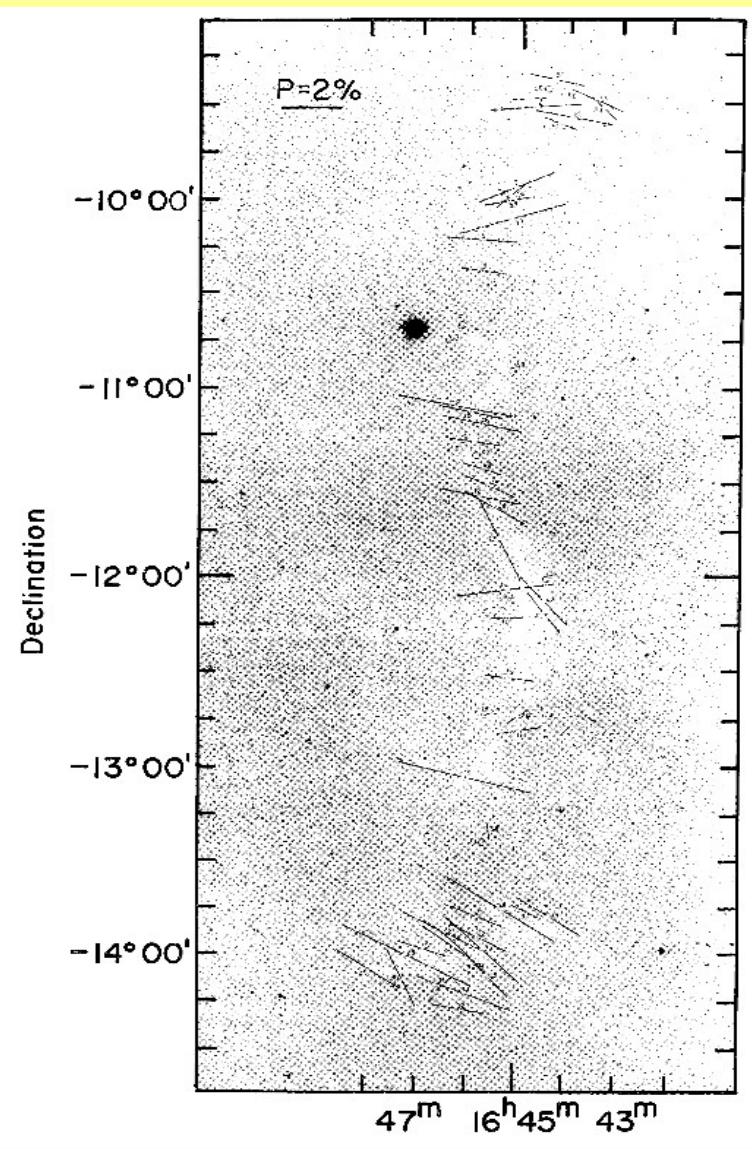
- Oblate Clouds within minor axes aligned with magnetic field direction
- Angular momentum of molecular clouds preferentially aligned with local magnetic field direction. Core angular momentum?
- Sub-critical cloud envelopes and supercritical cloud cores
- $B \sim n^{1/2}$



Basu & Mouschovias 1995

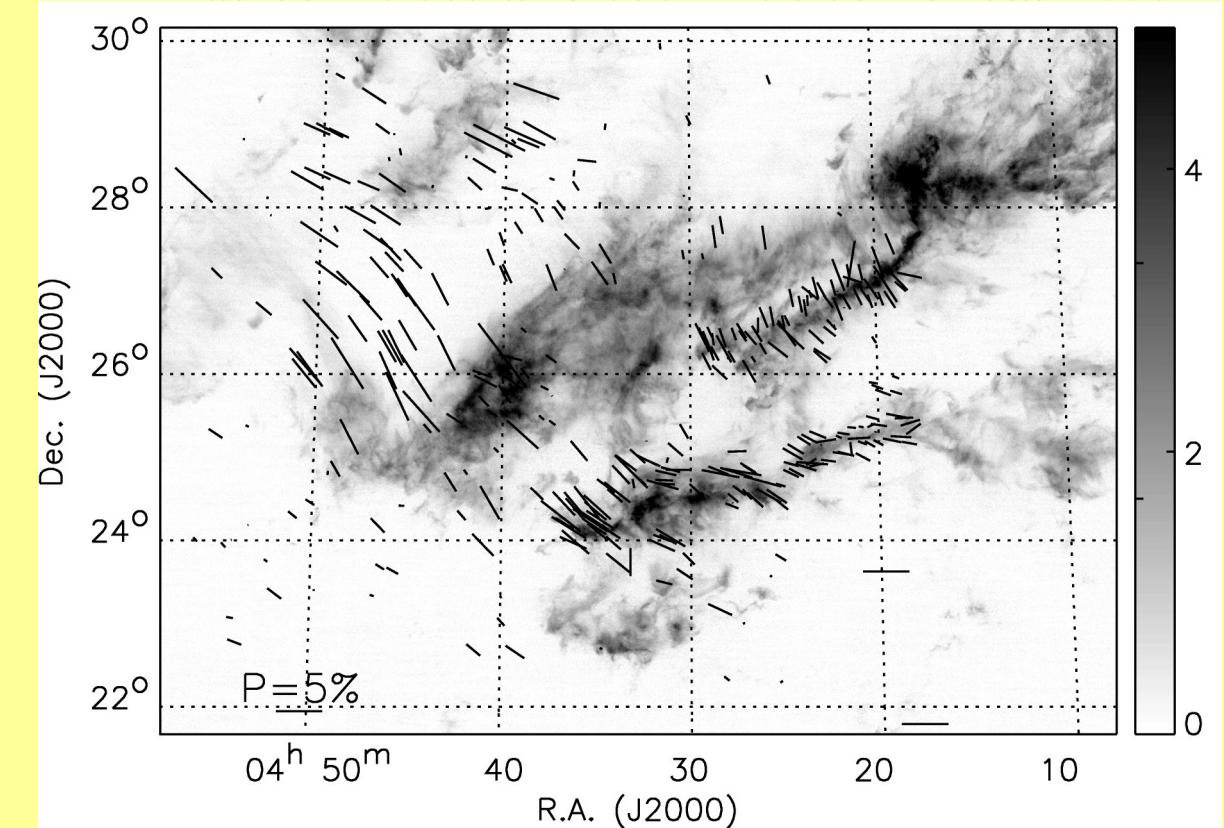
# Optical Polarization Studies

L204: McCutcheon et al 1986



Polarization of background starlight  
Av ~ few mag.

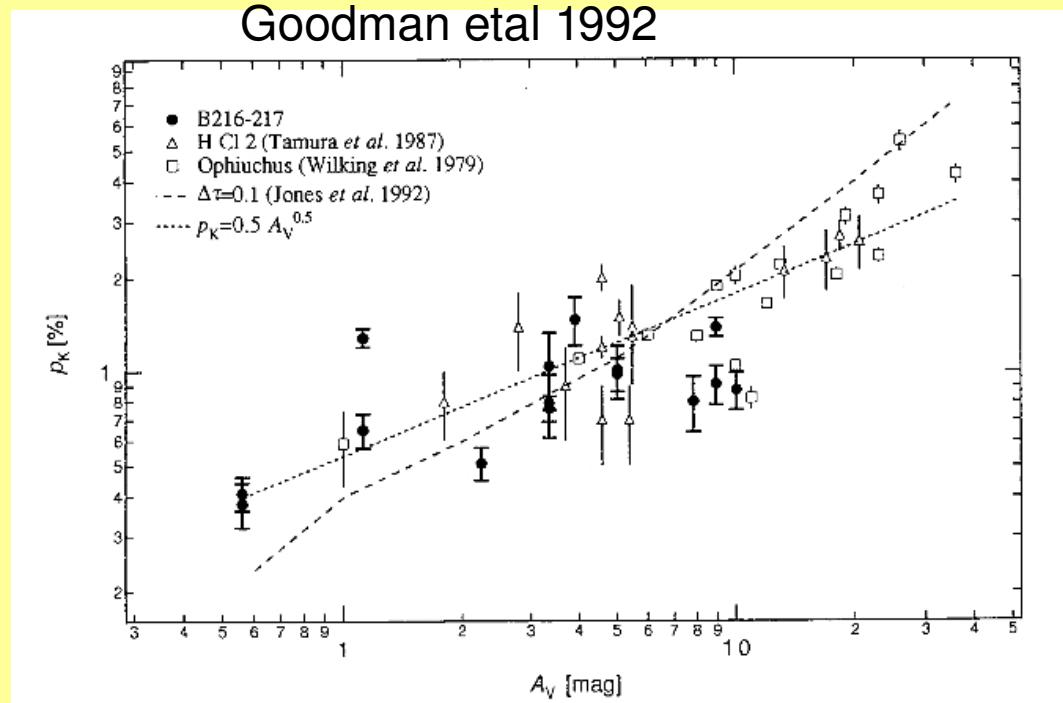
Taurus Molecular Cloud: Goldsmith et al 2008



# Near Infrared Polarimetry

Goodman et al 1992, 1995

- IR polarization angles similar to optical polarization angles
- Weak dependence of  $p_K$  with  $A_V$

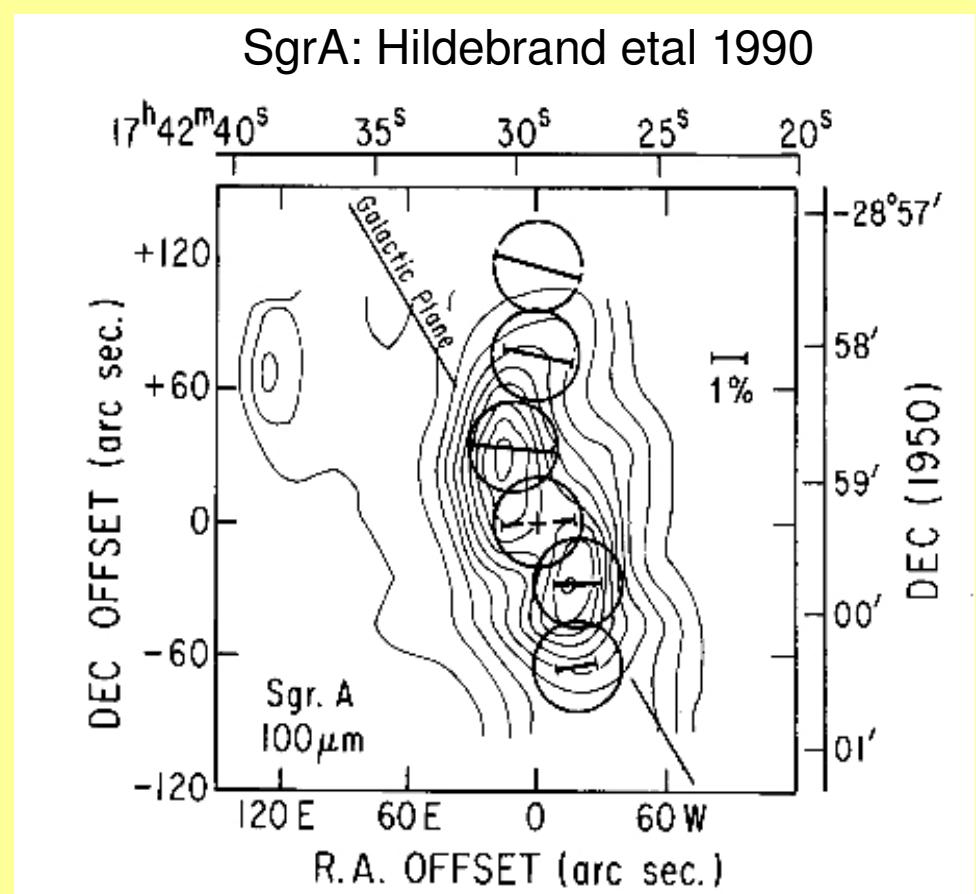
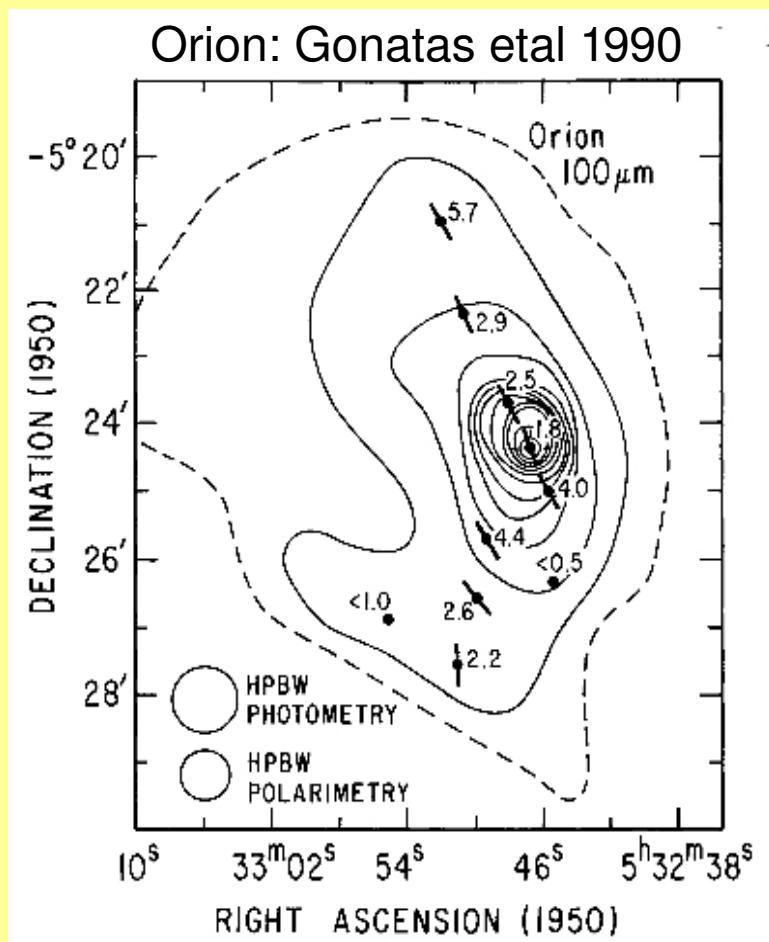


CONCLUDE:

- Polarization inefficiency in dense regions
- K band polarization may arise from dust within cloud envelope

# Polarization of Far Infrared/Submm Emission

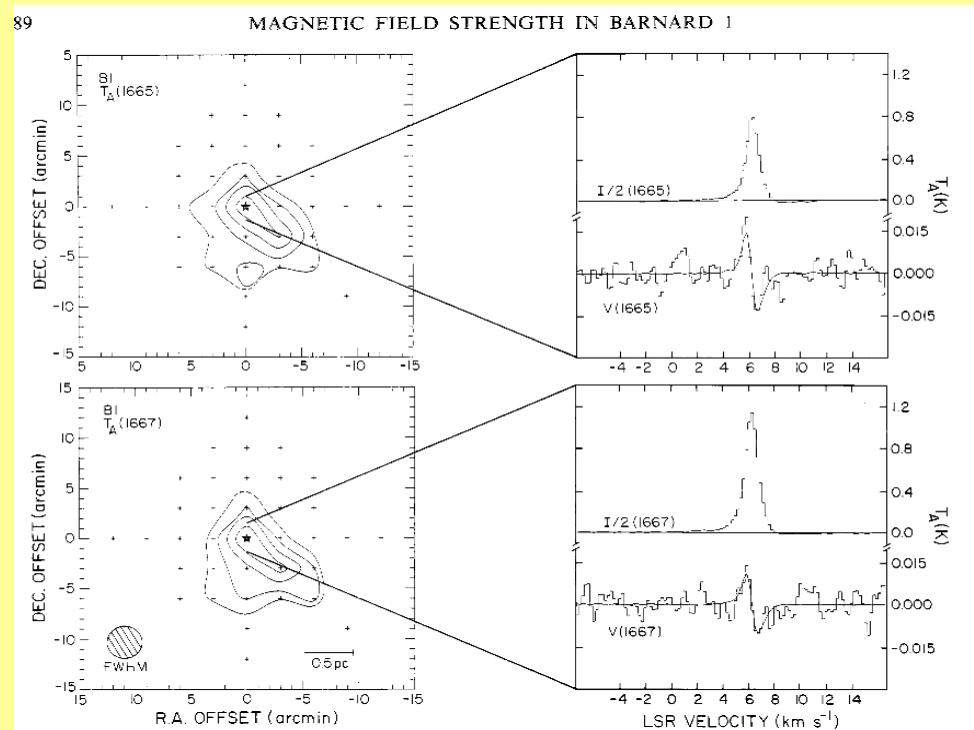
Directly probes magnetic field direction in *dense component* of clouds



# Observations of Magnetic Field Strengths

## OH Zeeman Measurements

- Before 1983: < 15-30  $\mu\text{G}$
- Orion B:  $38+/- 1 \mu\text{G}$   
(Crutcher & Kazes 1983)
- Massive cores: 15-70  $\mu\text{G}$   
(Crutcher et al 1987)
- B1 Dark Cloud:  $27+/- 4 \mu\text{G}$   
(Goodman et al 1989)



MAGNETIC MOLECULAR CLOUDS: INDIRECT EVIDENCE FOR MAGNETIC SUPPORT  
AND AMBIPOLEAR DIFFUSION

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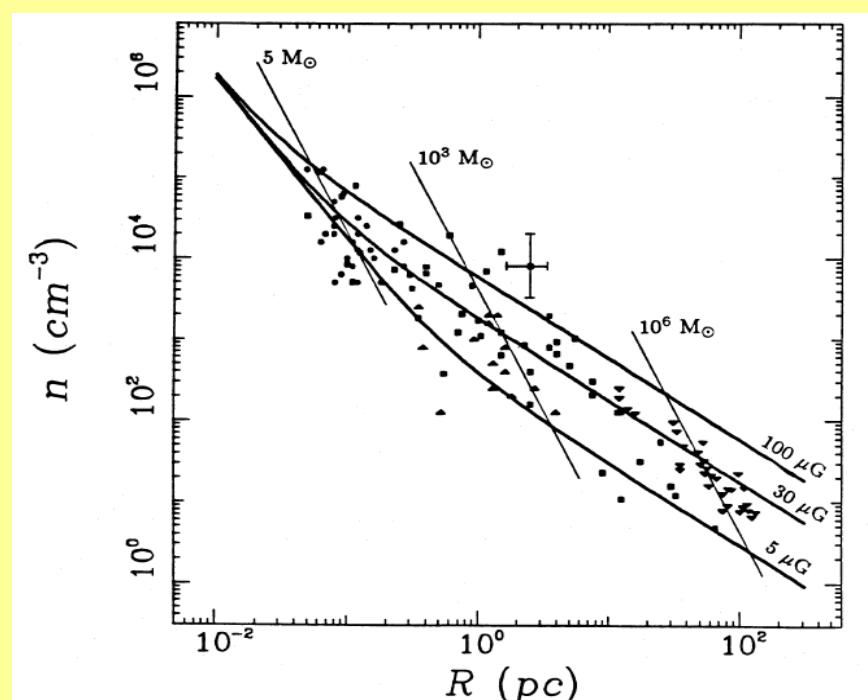
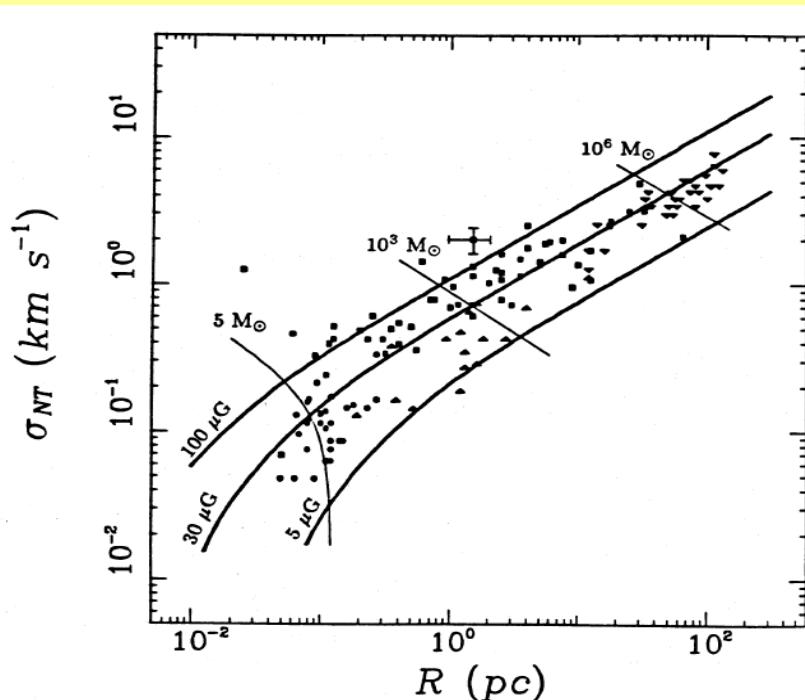
AND

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Received 1987 May 4; accepted 1987 December 17

# Accounting for Larson's Scaling relationships with magnetic waves

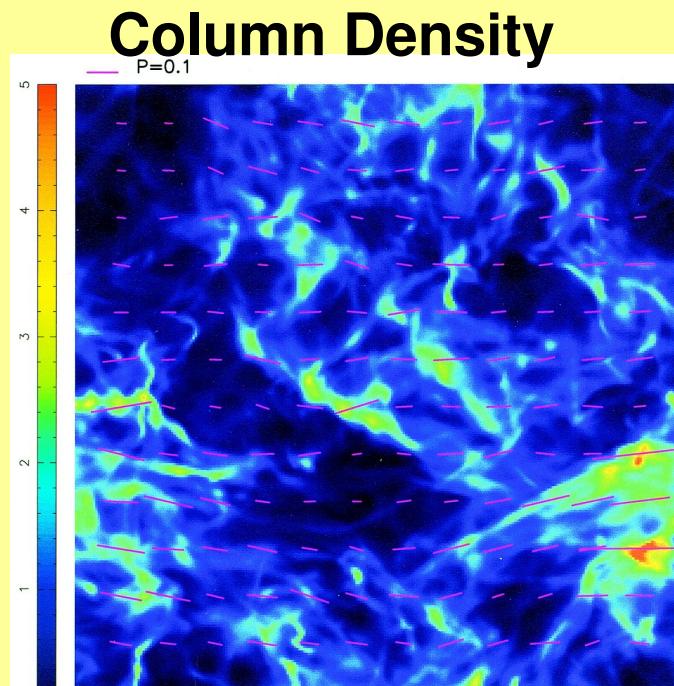


# Status in 1995

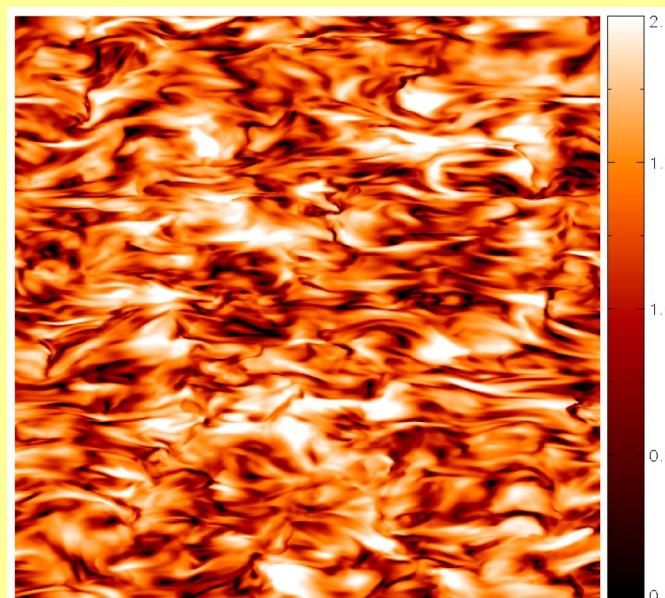
- Magnetic field directions/cloud morphology provided ambiguous interpretations
- Zeeman measurements (Crutcher 1999)
  - Equipartition between kinetic and magnetic energies
  - $\sigma_v \sim v_A$
  - $M/\Phi \sim 2x$  critical value
  - $B \sim n^{1/2}$
- $M/\Phi$  in dense core regime of clouds was highly uncertain

# Question for Discussion

To what degree are the observed motions in molecular clouds due to MHD turbulence (waves)?



**3D slice of  $v_z$**



B —————→

Ostriker, Stone,  
Gammie 2001