

Polarized Light from Star-Forming Regions

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Protostars & Planets IV, Santa Barbara, 1998

What good is it?

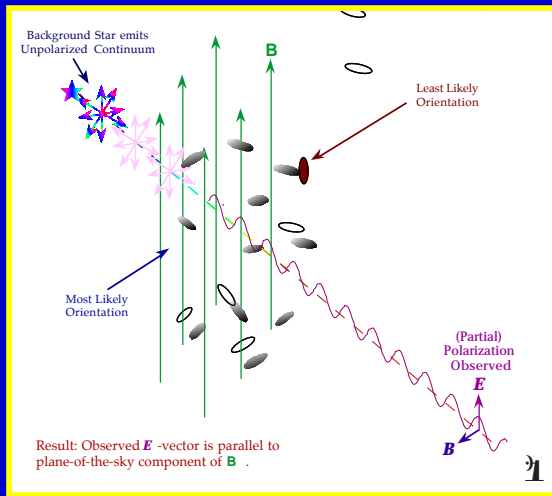
- **Magnetic fields** key to star-formation physics on many scales
 - polarization produced by aligned grains is currently the *only* way to map B_{\perp}
- **Internal structure of circumstellar nebulae** usually highly obscured
 - **scattered-light polarimetry** gives insight into YSO/disk/outflow geometry
- Excellent source of information on **dust properties**

All since PPIII...

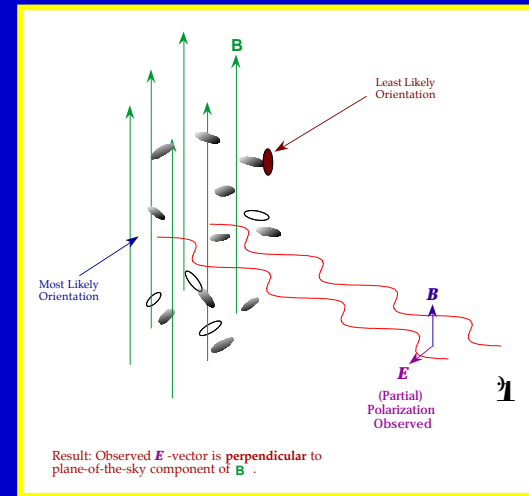
- Realization that using **background starlight polarimetry** is **dangerous** inside dark clouds
- Extensive mapping of **polarized thermal emission** from magnetically aligned grains
- Much progress on **grain & alignment theory**
- Successful **models and observations** of **scattering “disks”** around YSOs

Polarization 101

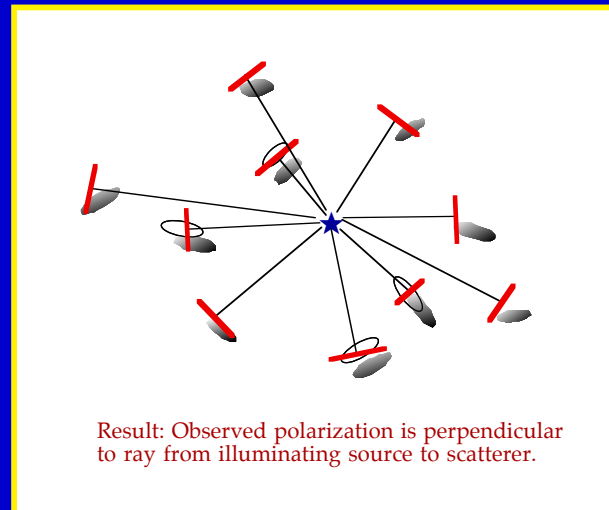
Absorption



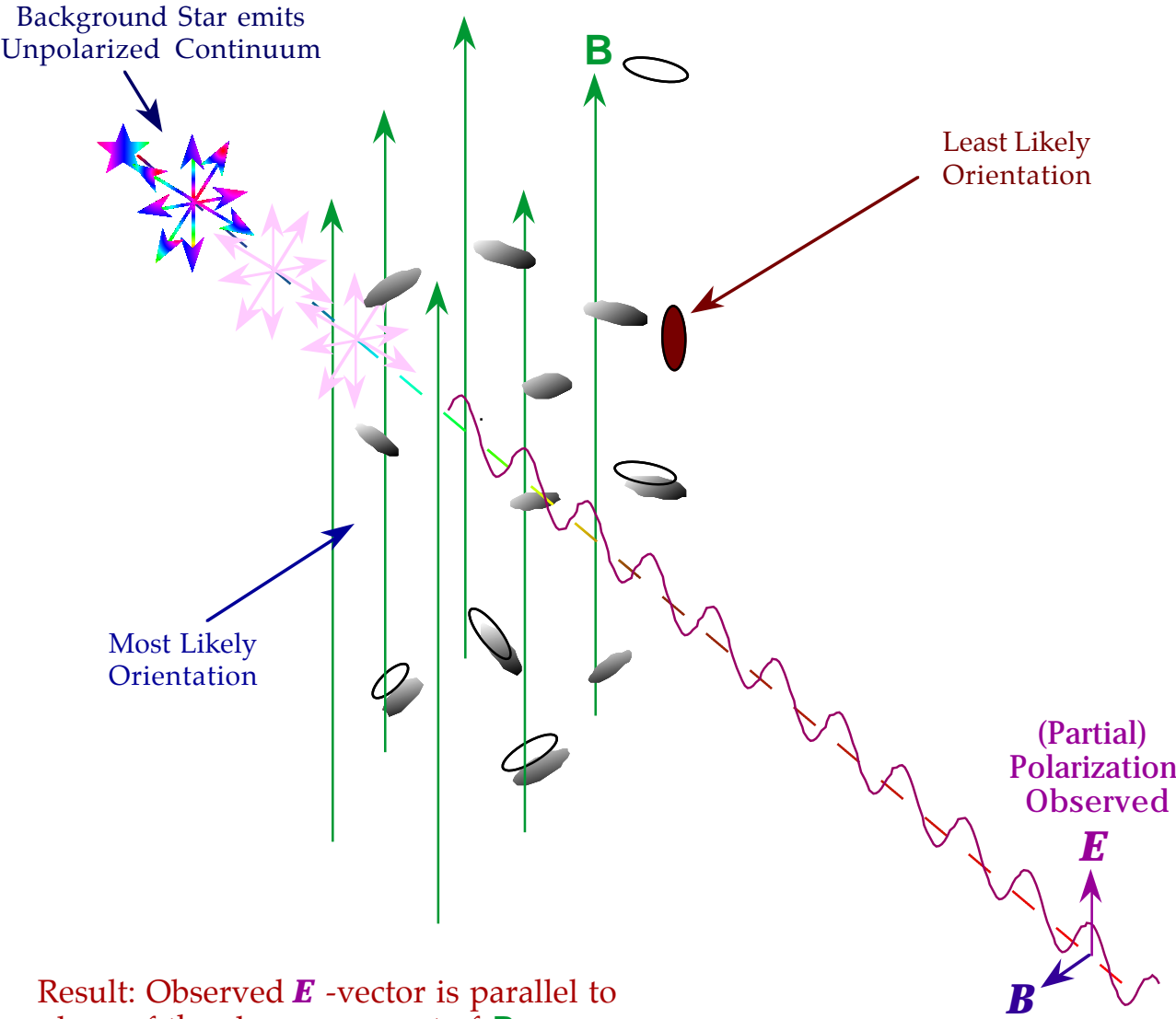
Emission



Scattering

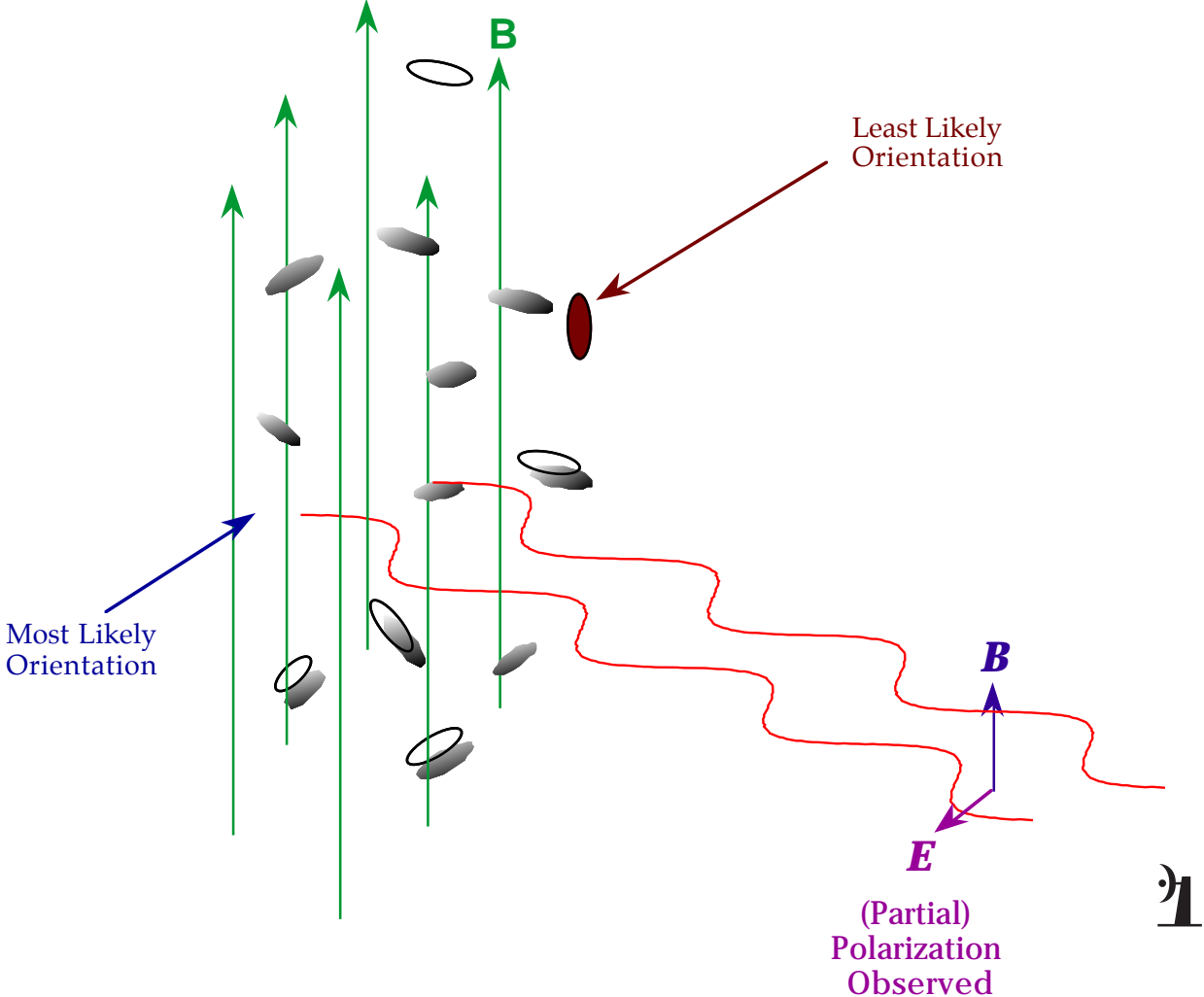


Polarization of Background Starlight



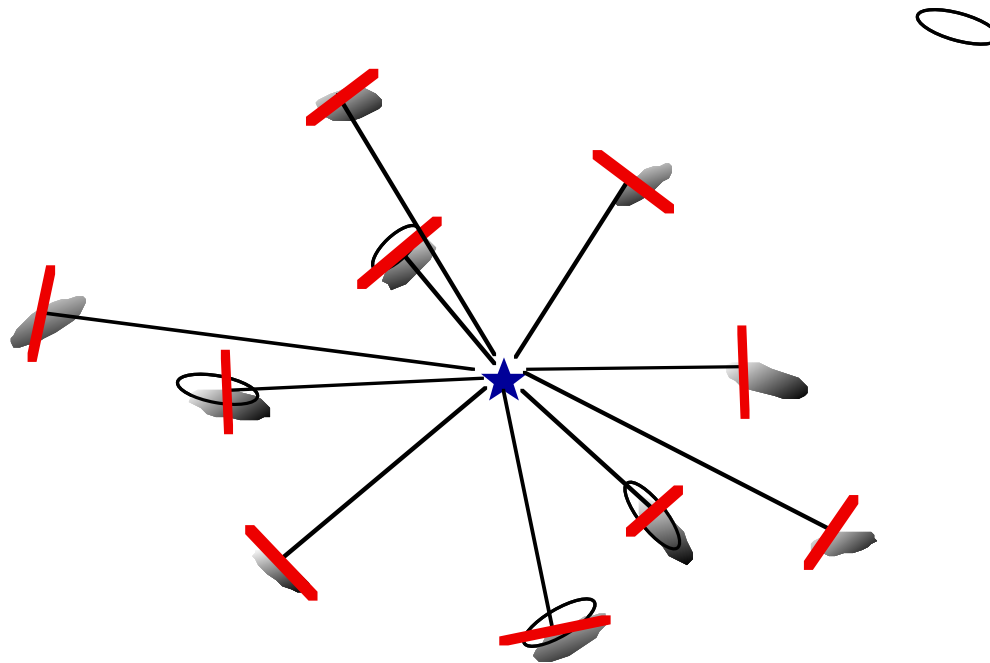
Result: Observed E -vector is parallel to plane-of-the-sky component of B .

Polarization of Thermal Radiation



Result: Observed E -vector is **perpendicular** to plane-of-the-sky component of B .

Polarization of Scattered Starlight

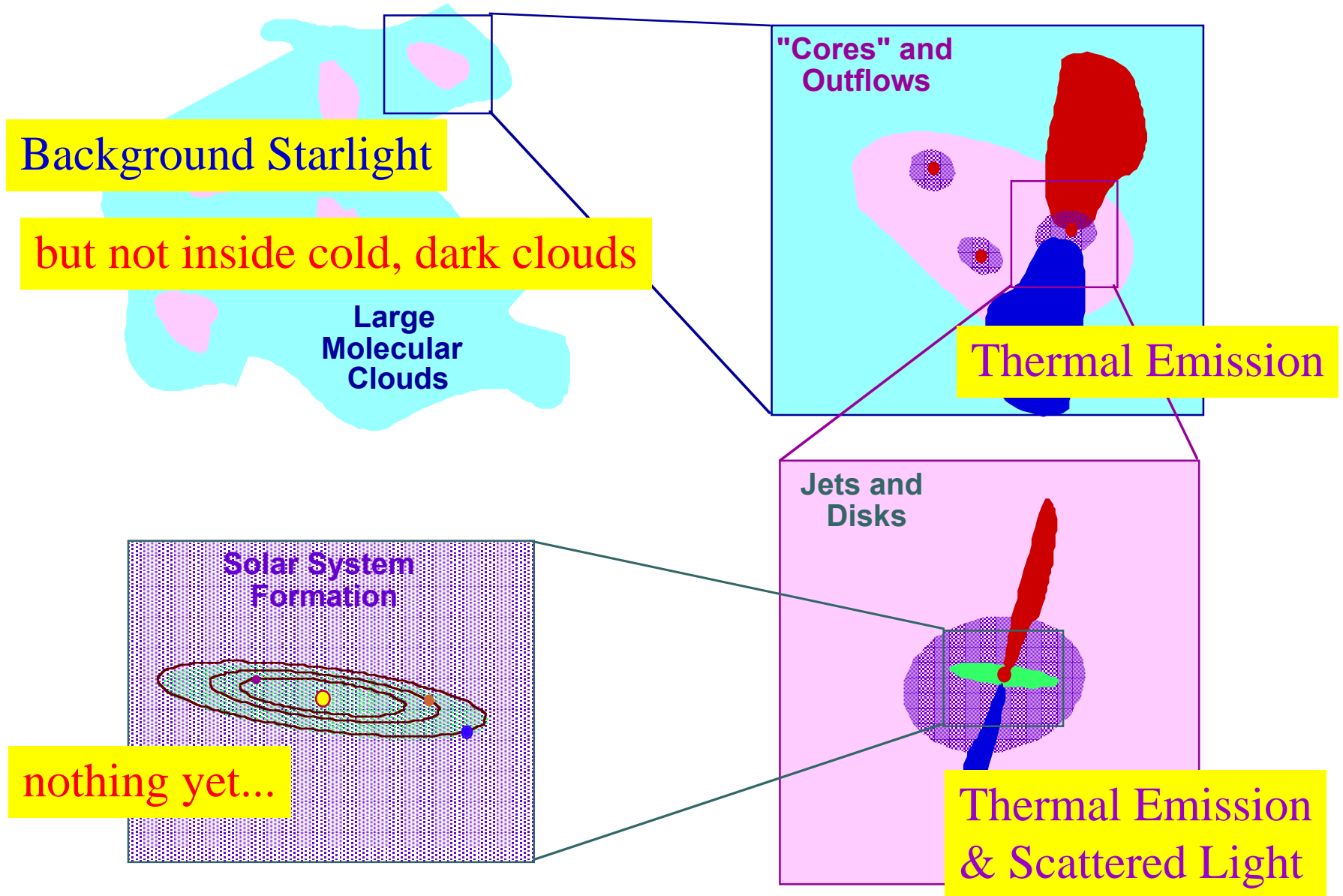


Result: Observed polarization is perpendicular to ray from illuminating source to scatterer.

WARNING:

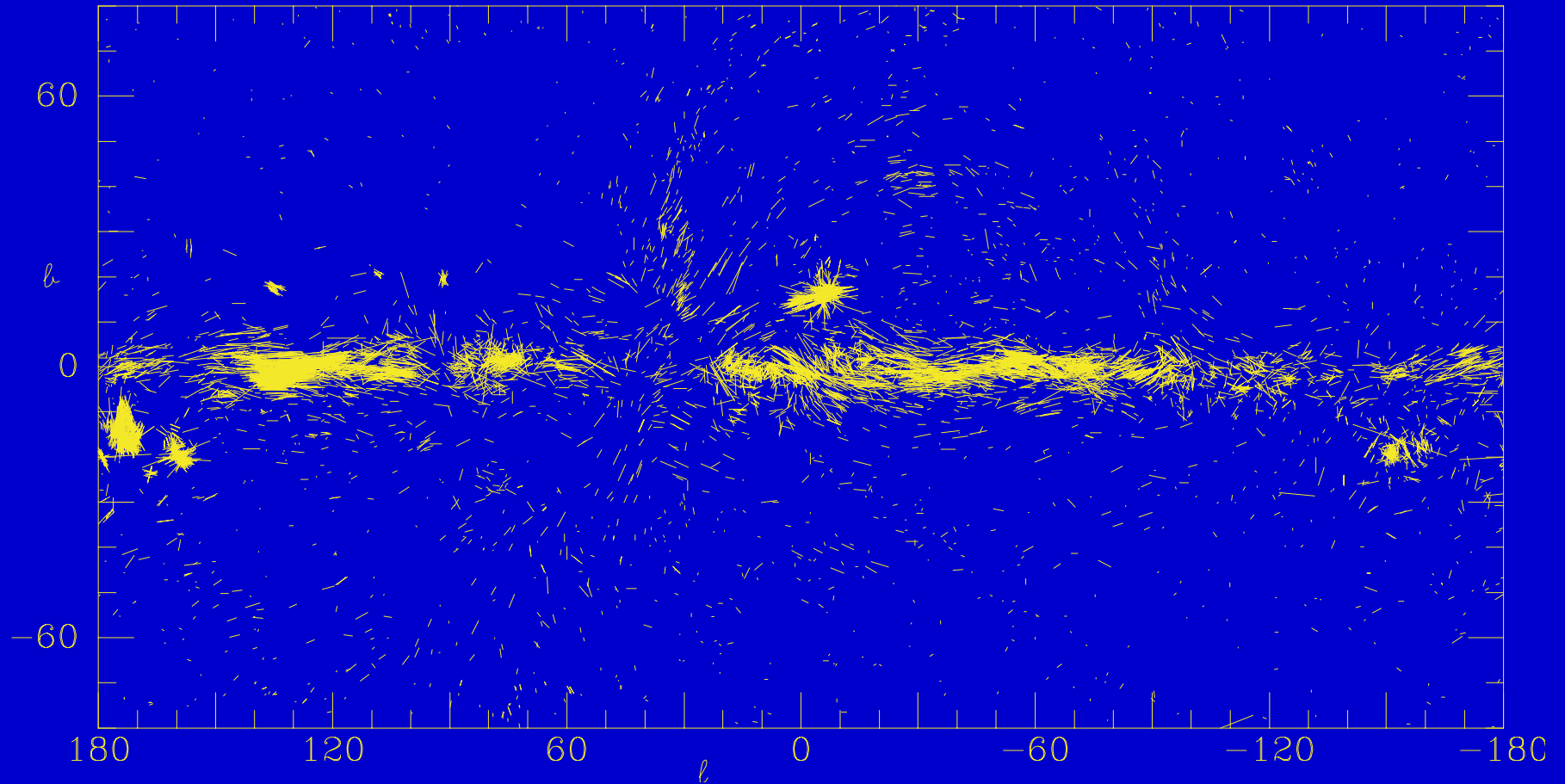
This illustration is for single scattering, and a single source of illumination.

What's good where (now)?



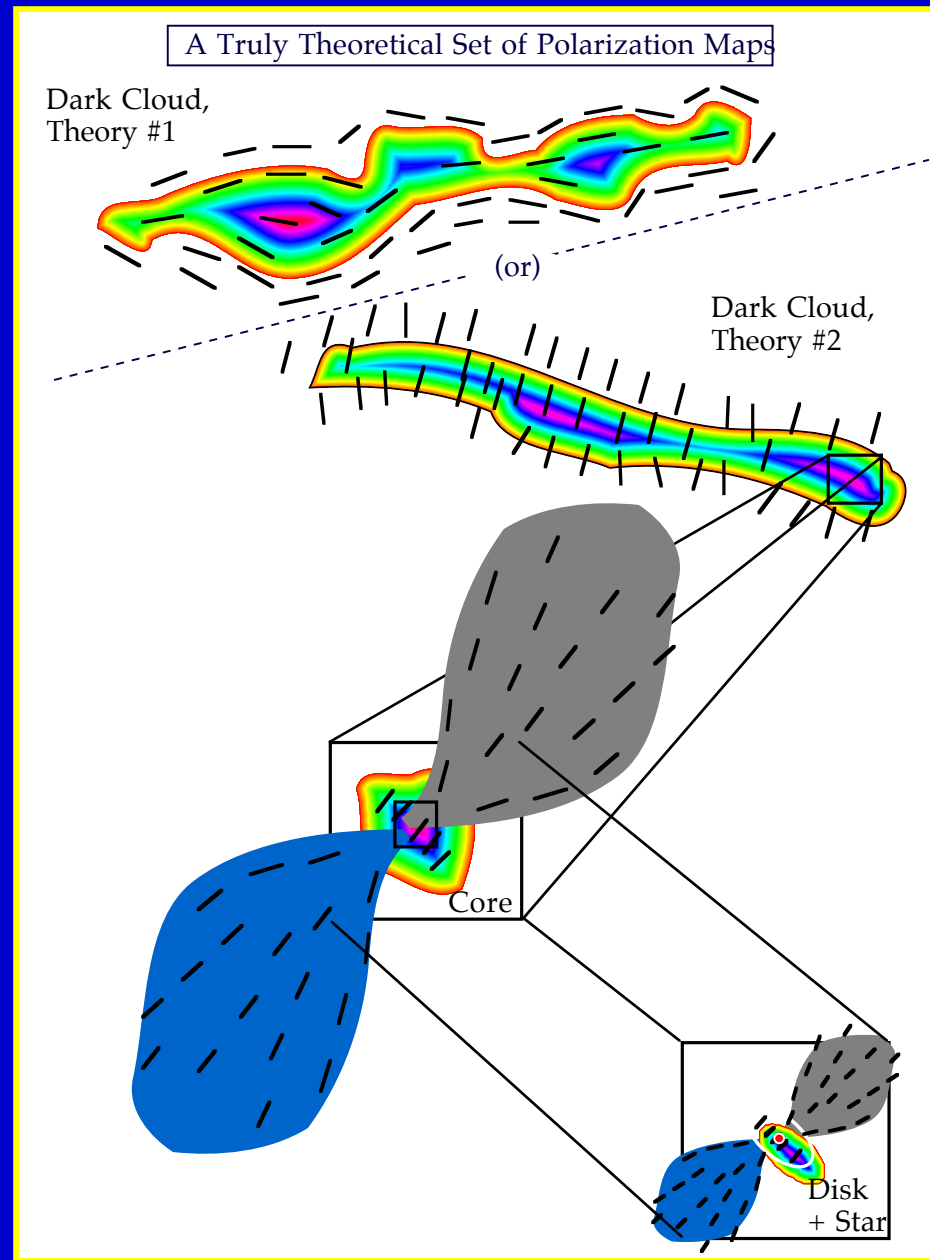
The Galaxy

Serkowski, Mathewson & Ford, et al.



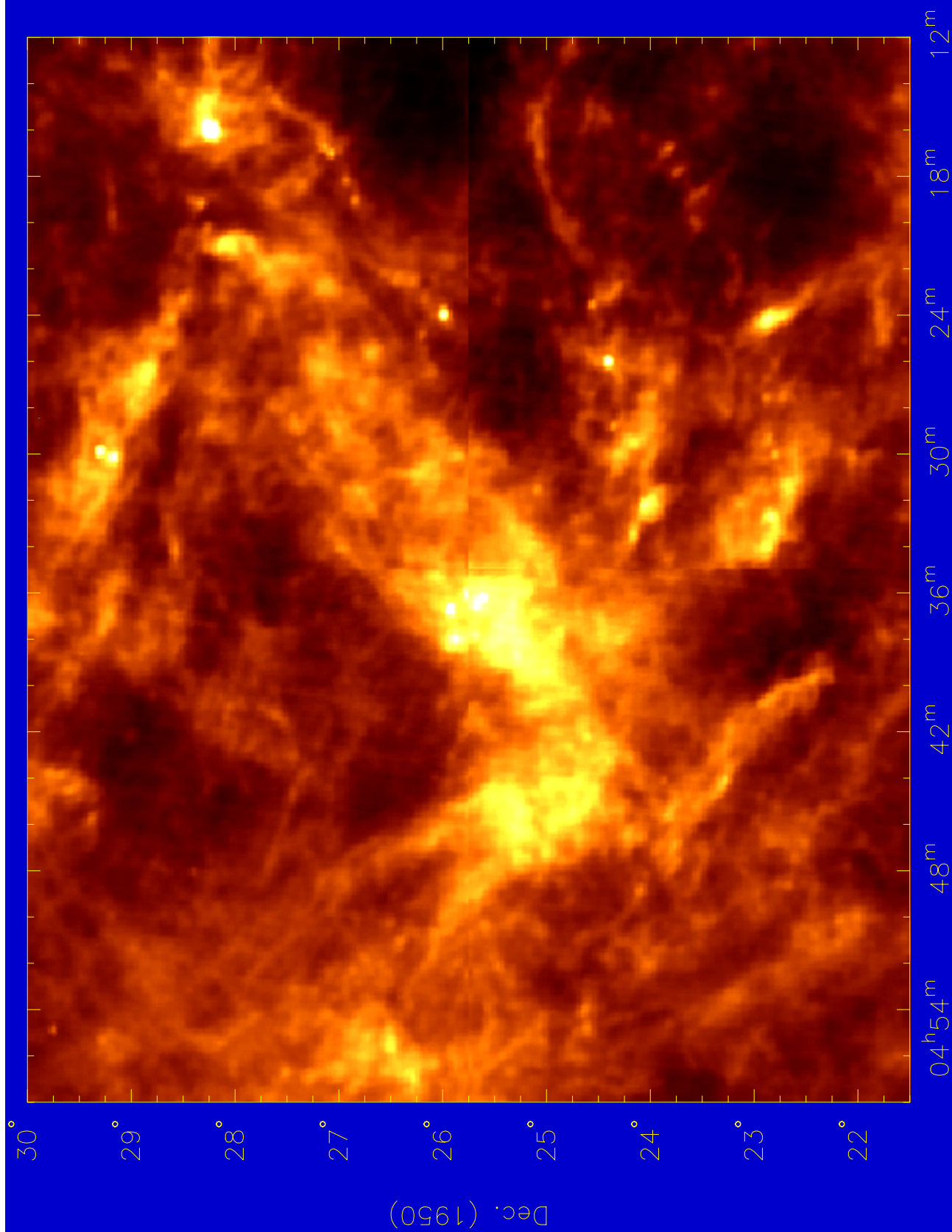
Magnetic Fields

Naïveté:
*The way
we once
thought
things might
be...*



Magnetic Fields

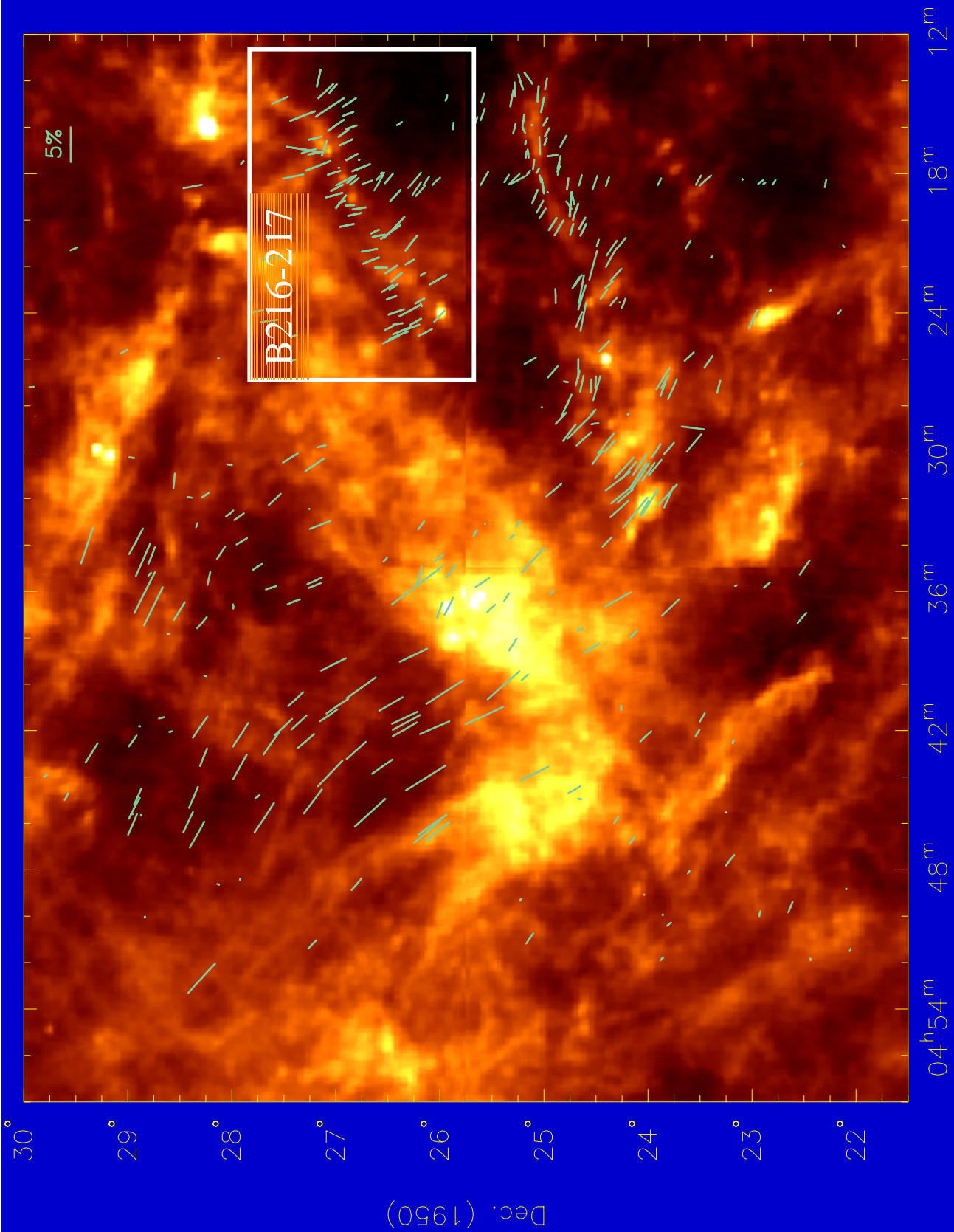
Dark Cloud Complexes: 1-10 pc scales



R.A. (1950)

Magnetic Fields

Dark Cloud Complexes: 1-10 pc scales



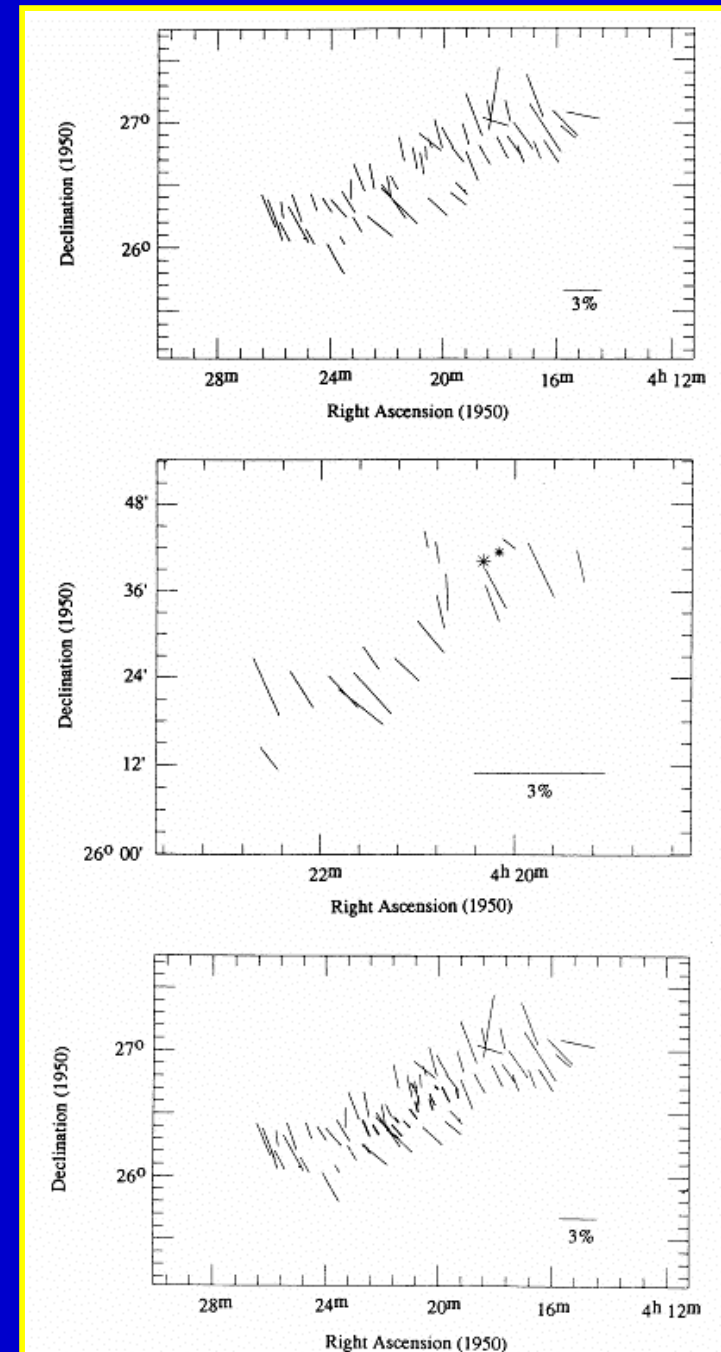
R.A. (1950)

Magnetic Fields

Cold Dark Clouds: Looking Inside(?)

Goodman et al. 1992

Magnetic Fields



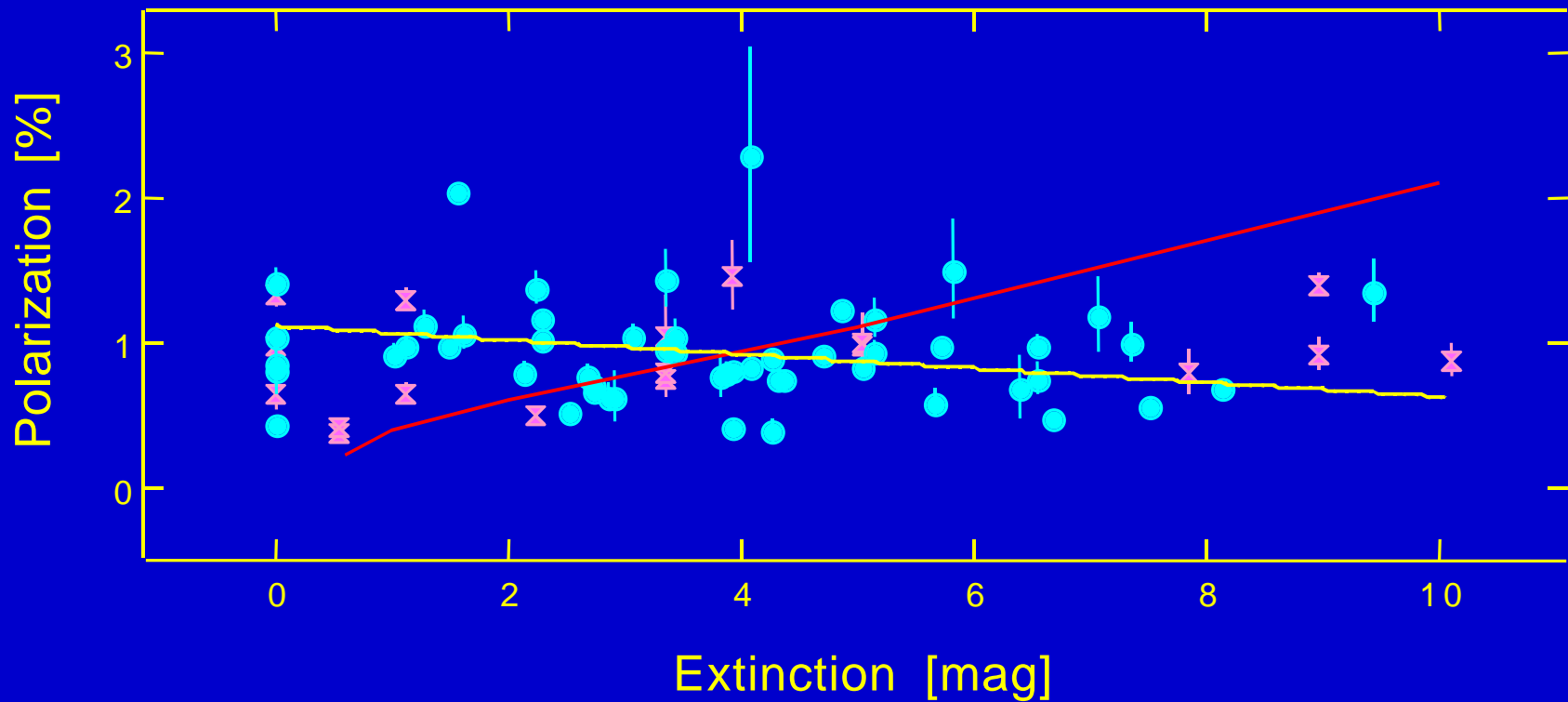
Cold Dark Clouds: (Not) Looking Inside

✕ B216-217 (Goodman et al. 1992)

— Galaxy (Jones, Klebe & Dickey 1992)

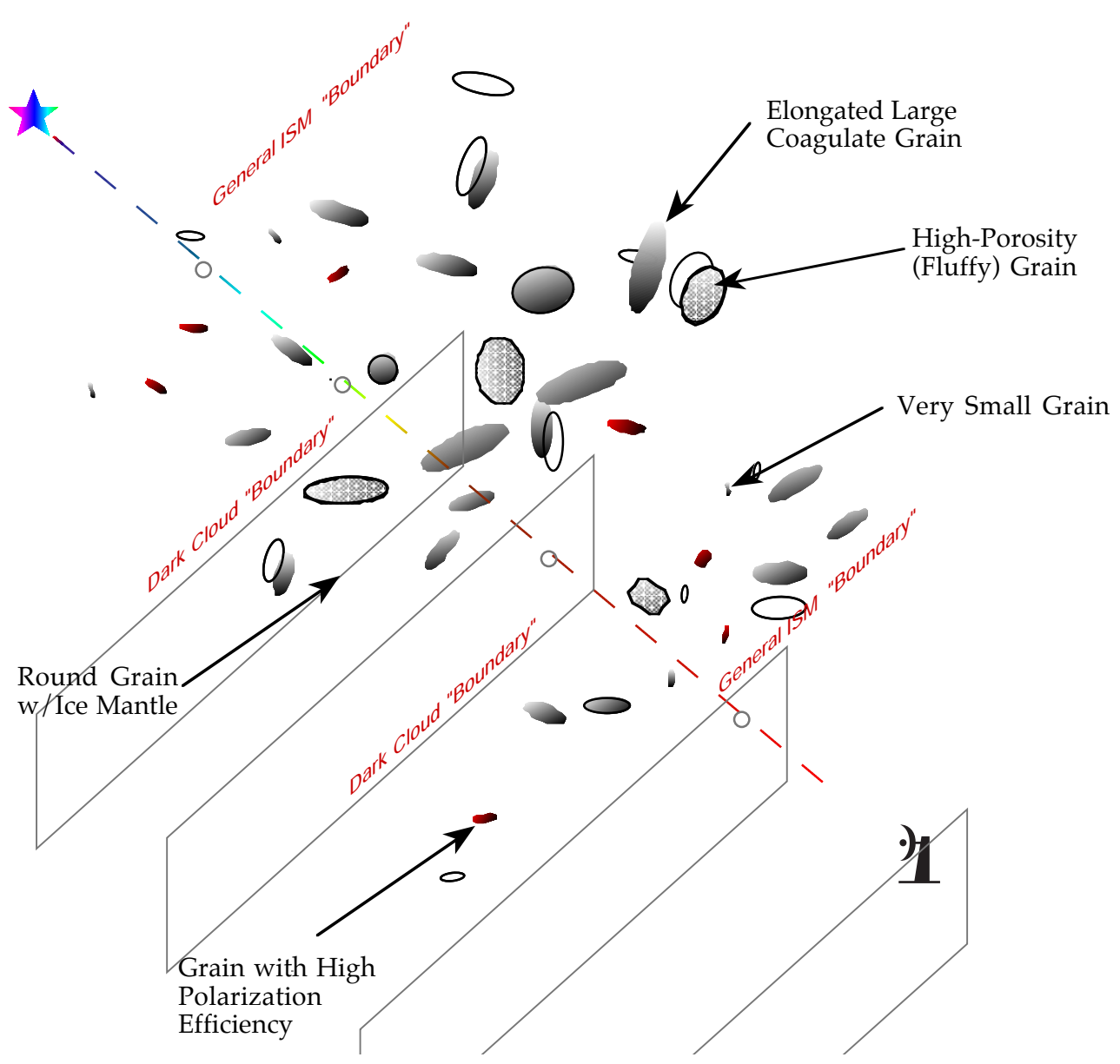
● L1755 (Goodman et al. 1995)

— Fit to these dark clouds

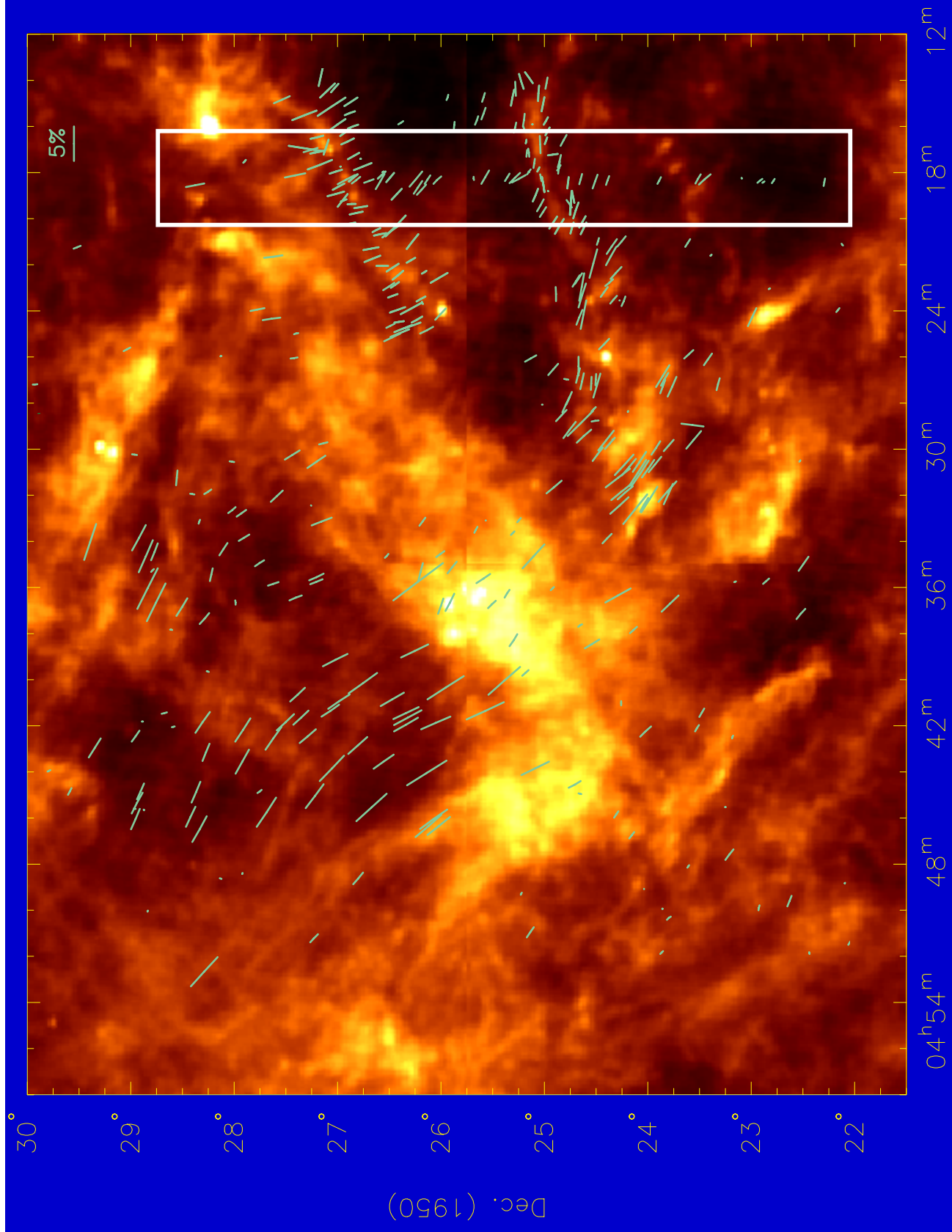


Magnetic Fields

"Not All Grains are Created Equal"



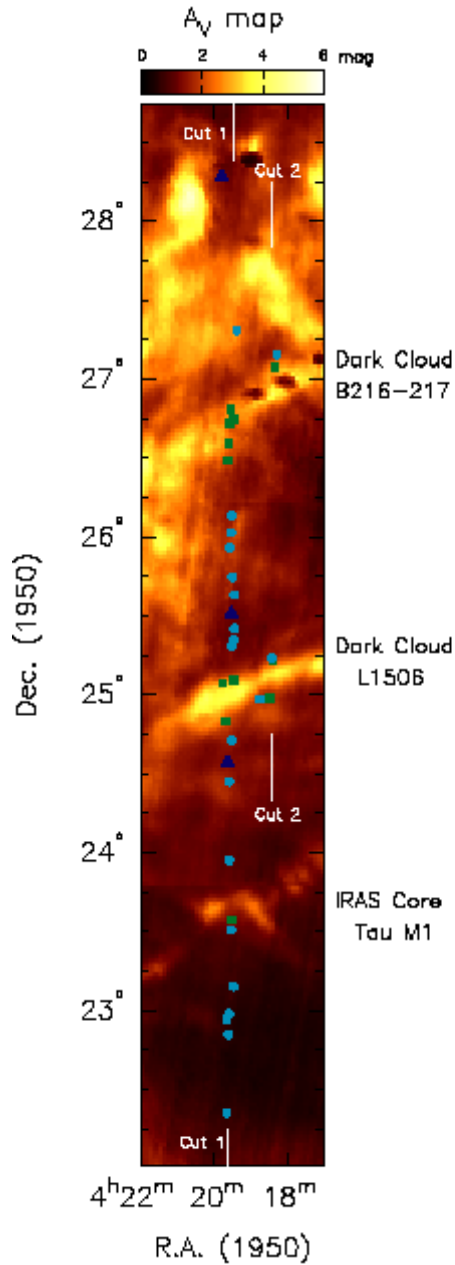
Dark Cloud Complexes: 1-10 pc scales



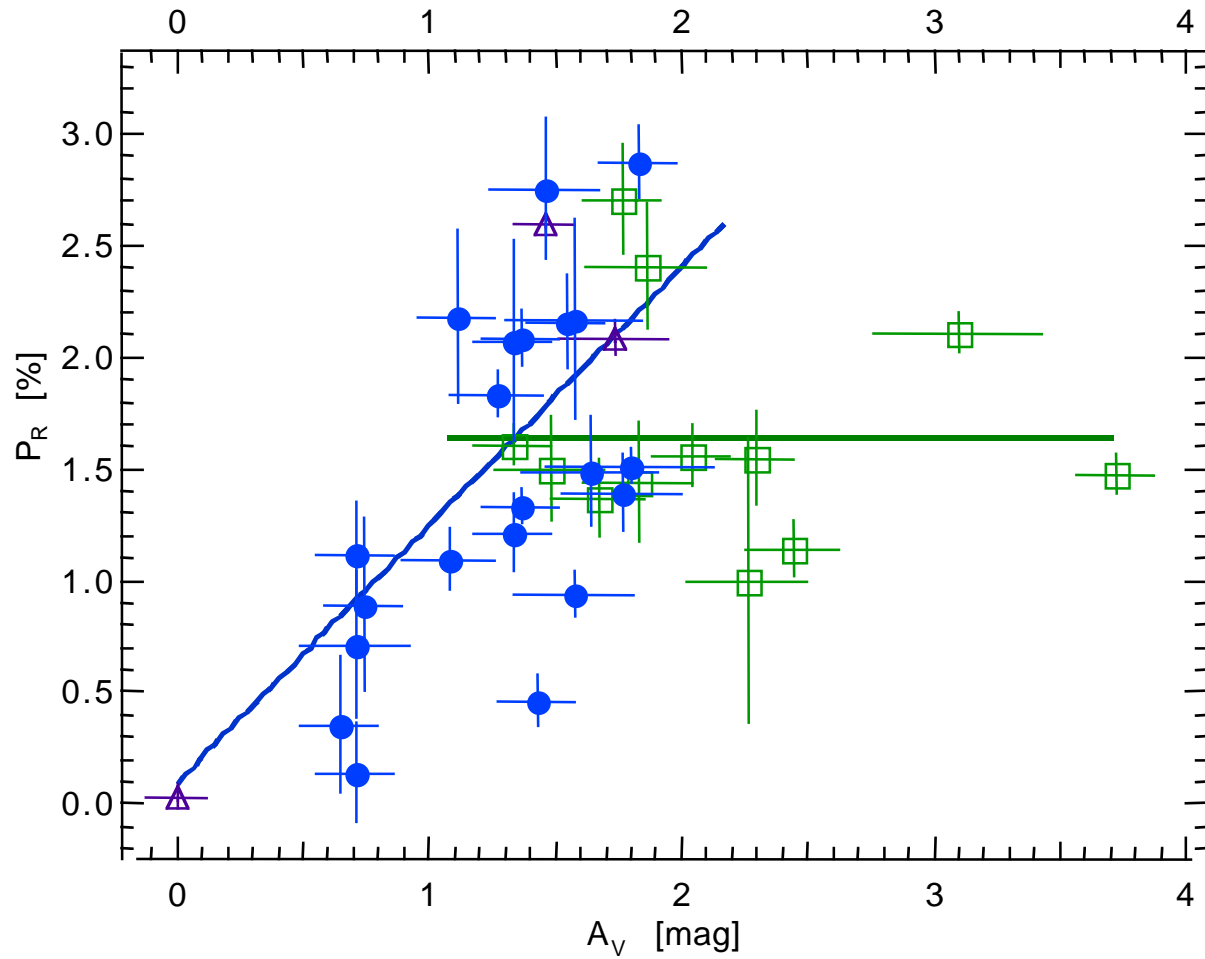
R.A. (1950)

Magnetic Fields

“Go no further than $A_V \sim 1.3$ mag.”



Magnetic Fields

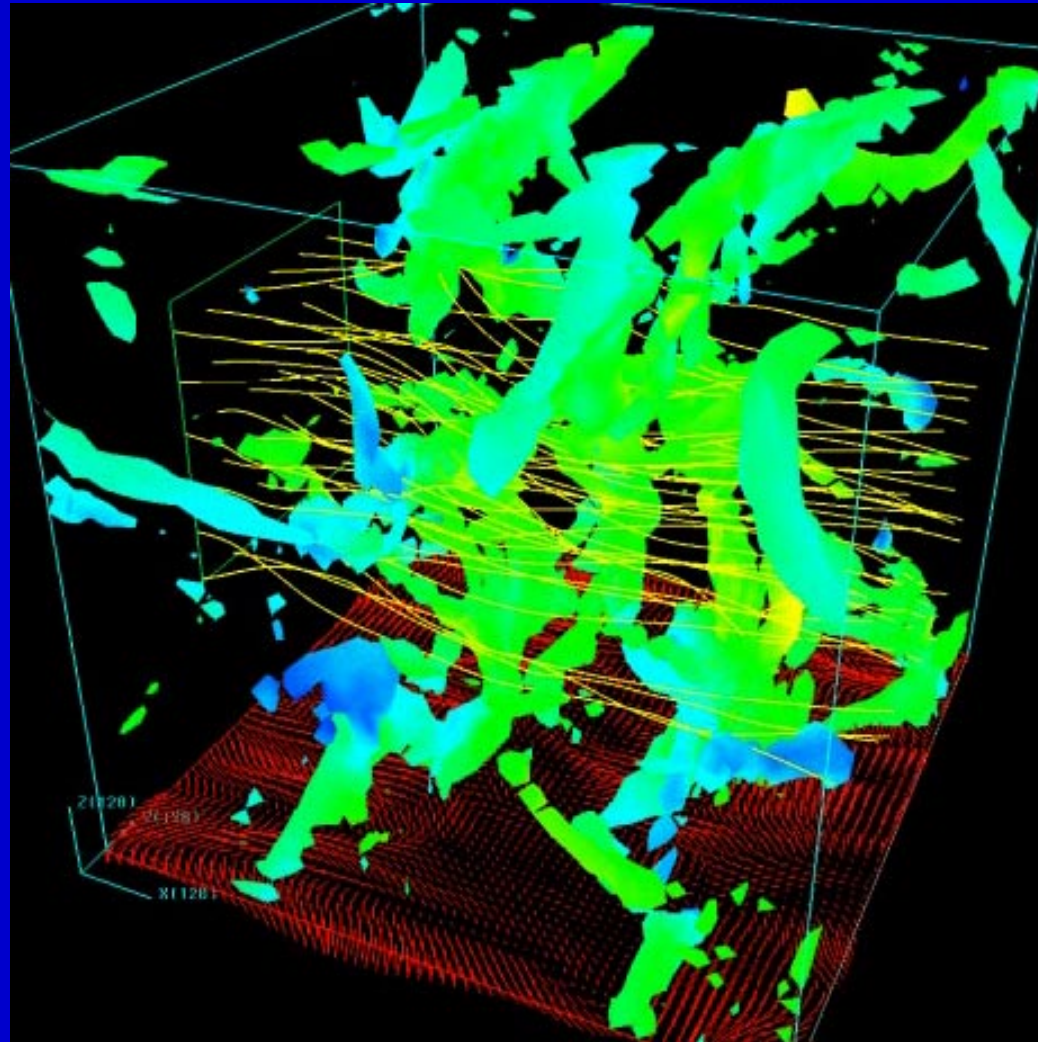


- Background to Cold Dark Cloud
- Background to General ISM

Arce et al. 1998

Dark Cloud Complexes: 1-10 pc scales

3D MHD simulation of Gammie, Stone & Ostriker (in prep.)



*Field lines
“look”
straight-ish,
even though
 B is
significant.*

Magnetic Fields

Thermal Emission Polarimetry

far-IR:

KAO

SOFIA

M3/Balloon

sub-mm:

JCMT, CSO

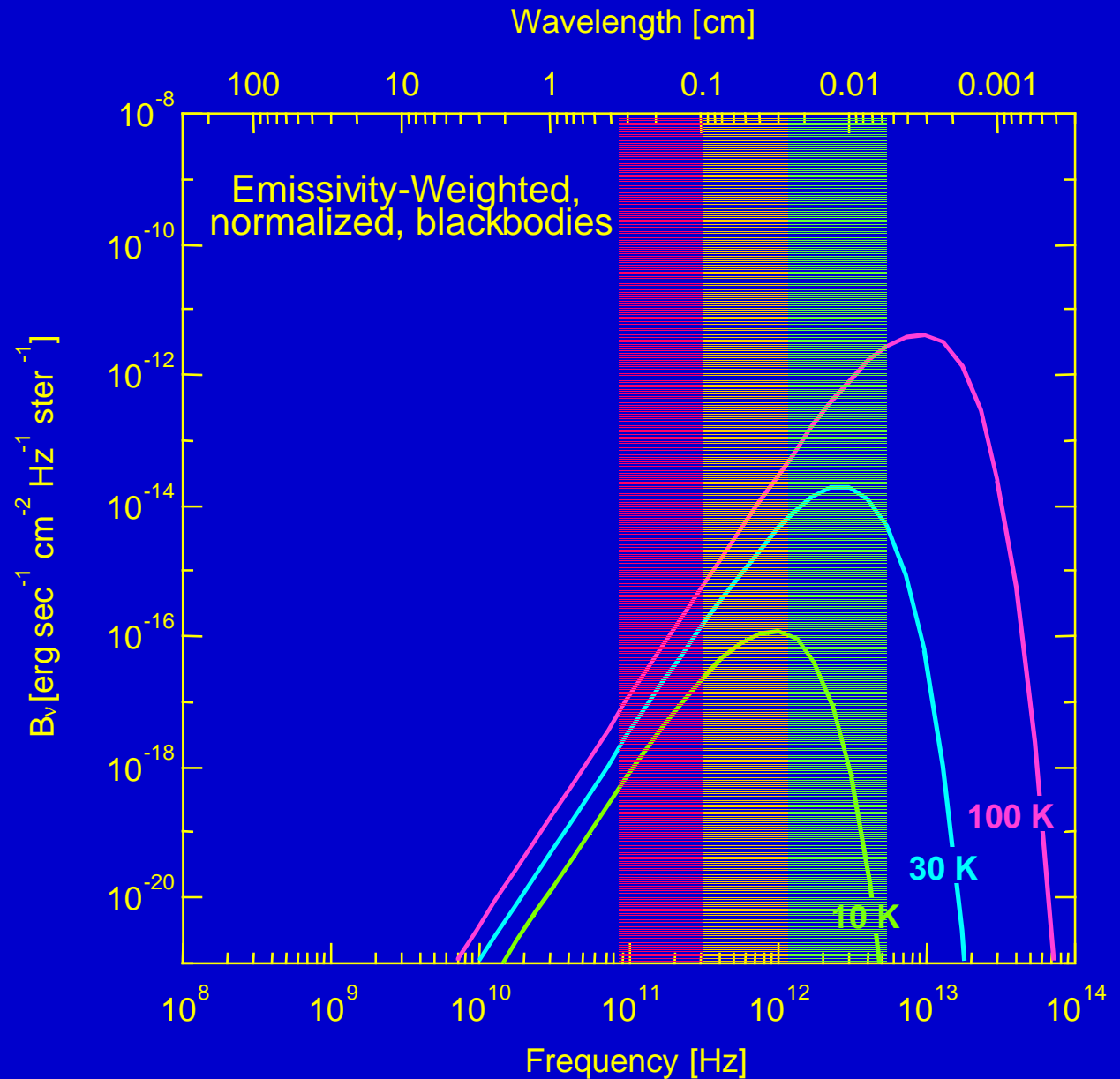
SMA

mm:

OVRO, BIMA

MMA

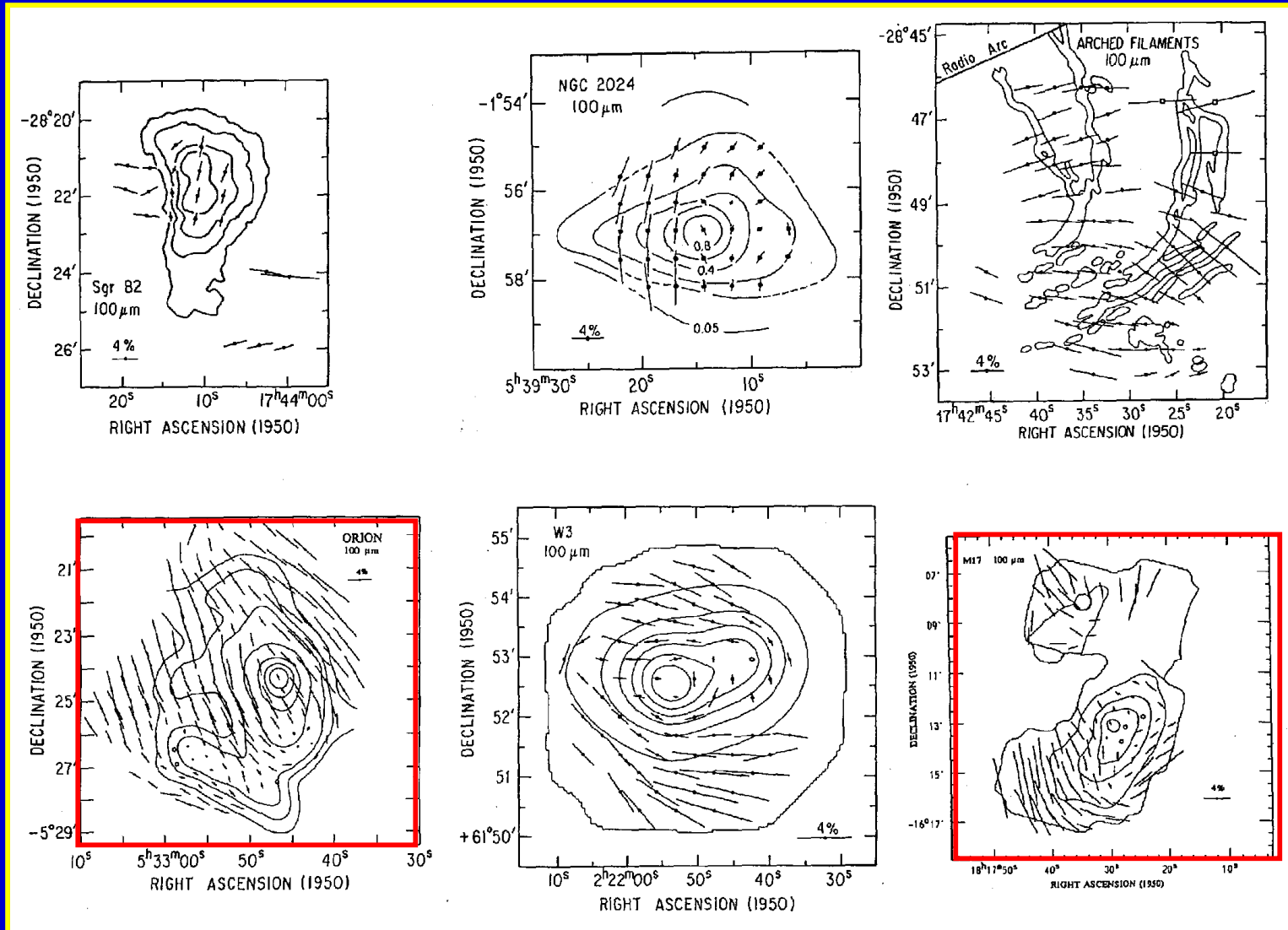
Magnetic Fields



Massive Star-Forming Regions

- Often “super-critical” ($E_{grav} > E_{mag}$)
- Typically forming complexes... how tangled is the field?
- Do outflows effect the field (or vice-versa)?

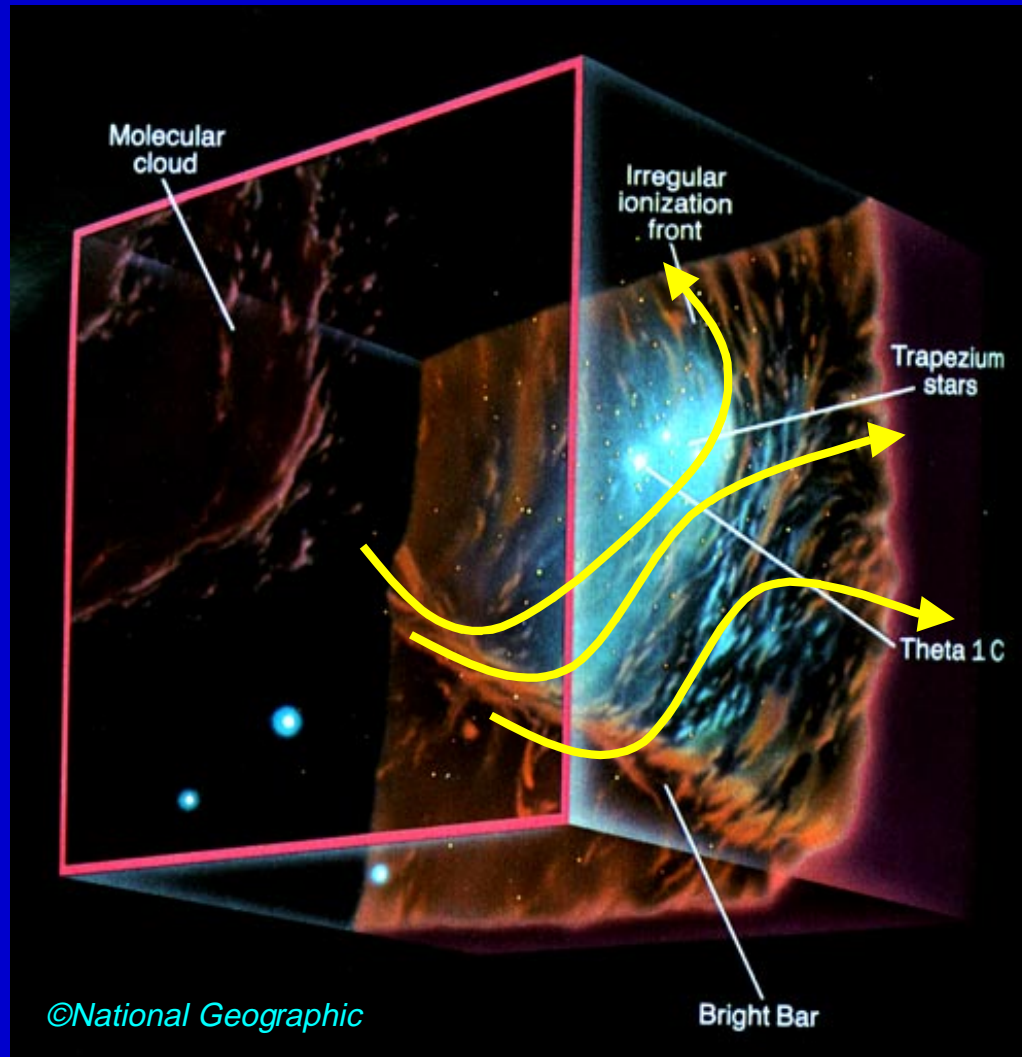
Massive Star-Forming Regions: Thermal Emission Polarimetry



KAO 100- μm polarimetry (Hildebrand et al. 1995)

Magnetic Fields

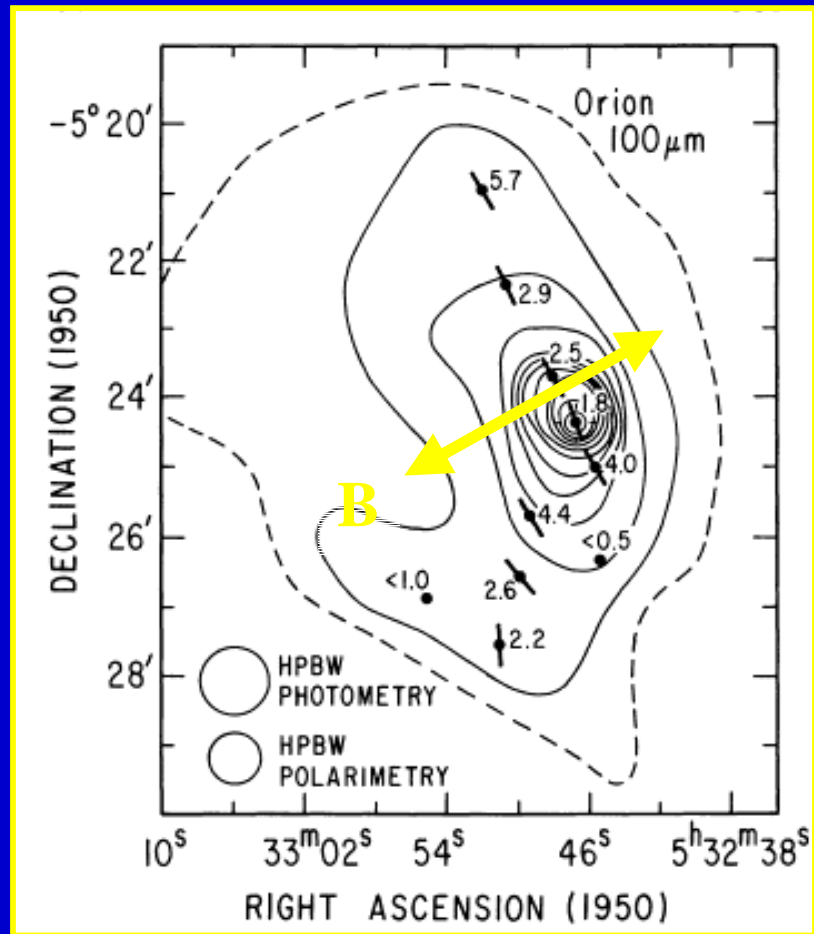
Massive Star-Forming Regions: Orion



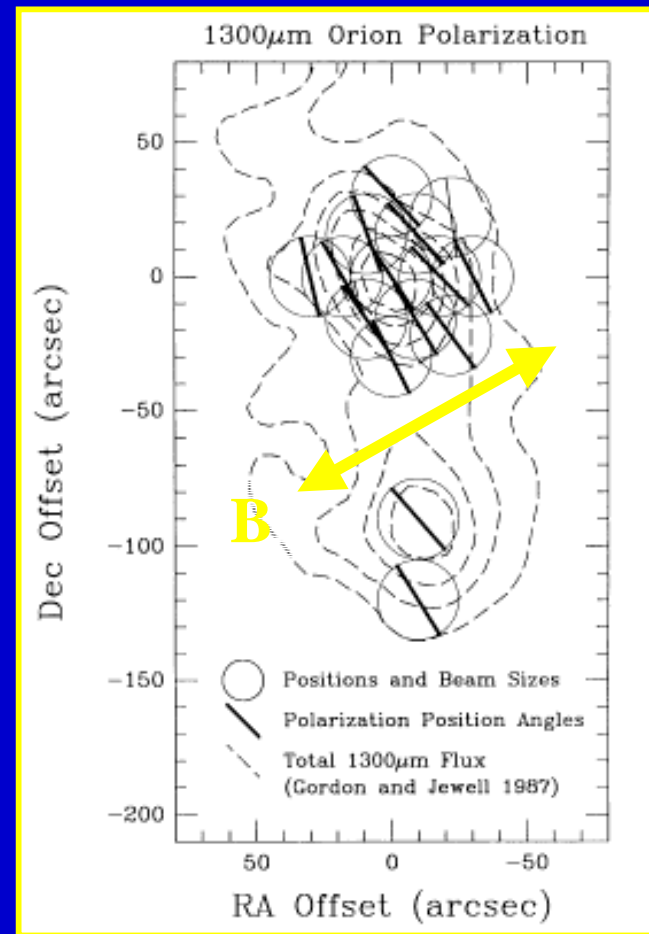
Magnetic Fields

Massive Star-Forming Regions: Orion

1990: KAO Polarimeter
(Gonatas et al.)



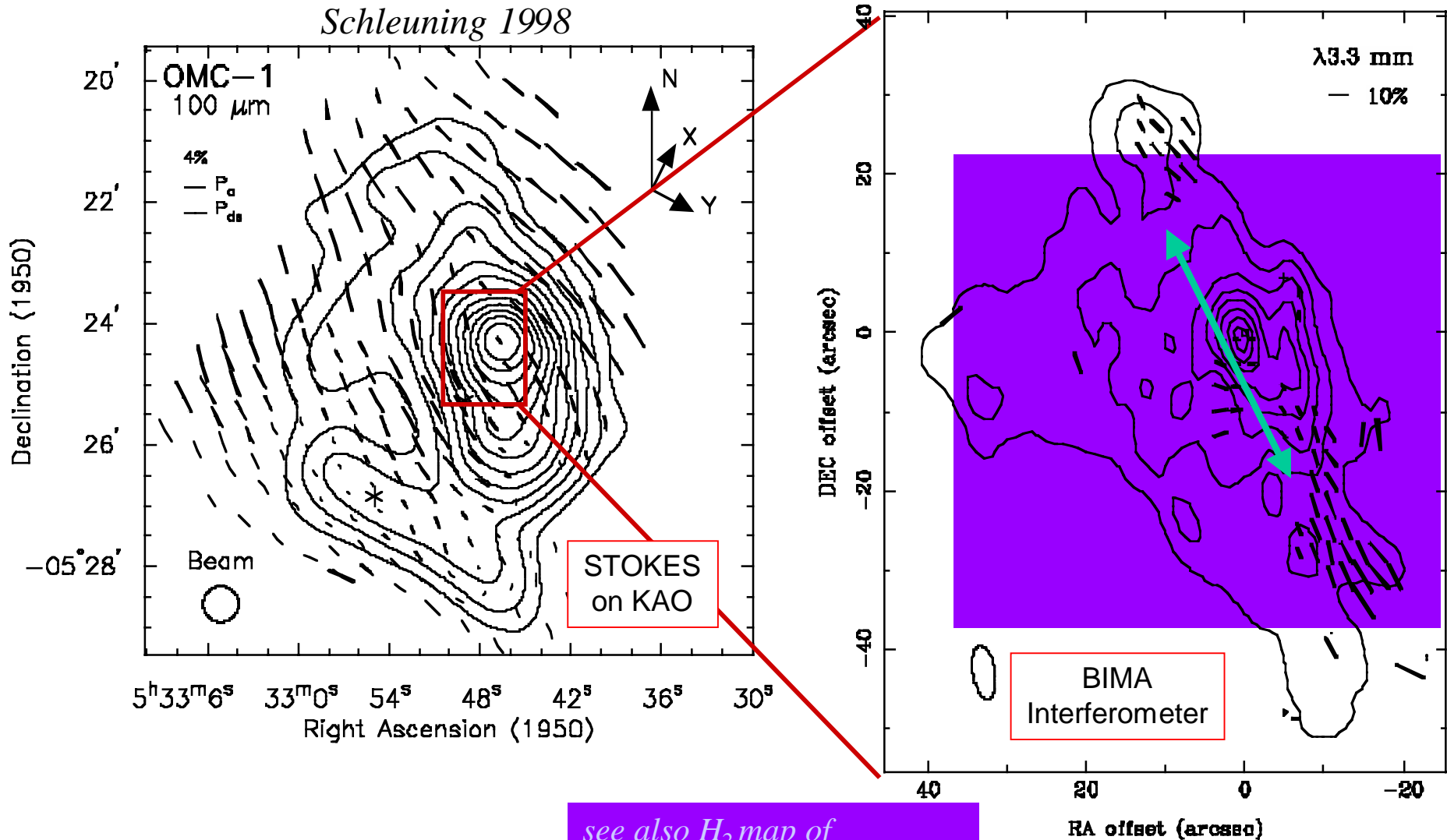
1991: MILLIPOL on NRAO 12-m
(Leach, Clemens, Kane & Barvainis)



Magnetic Fields

Zooming on Orion BN/KL

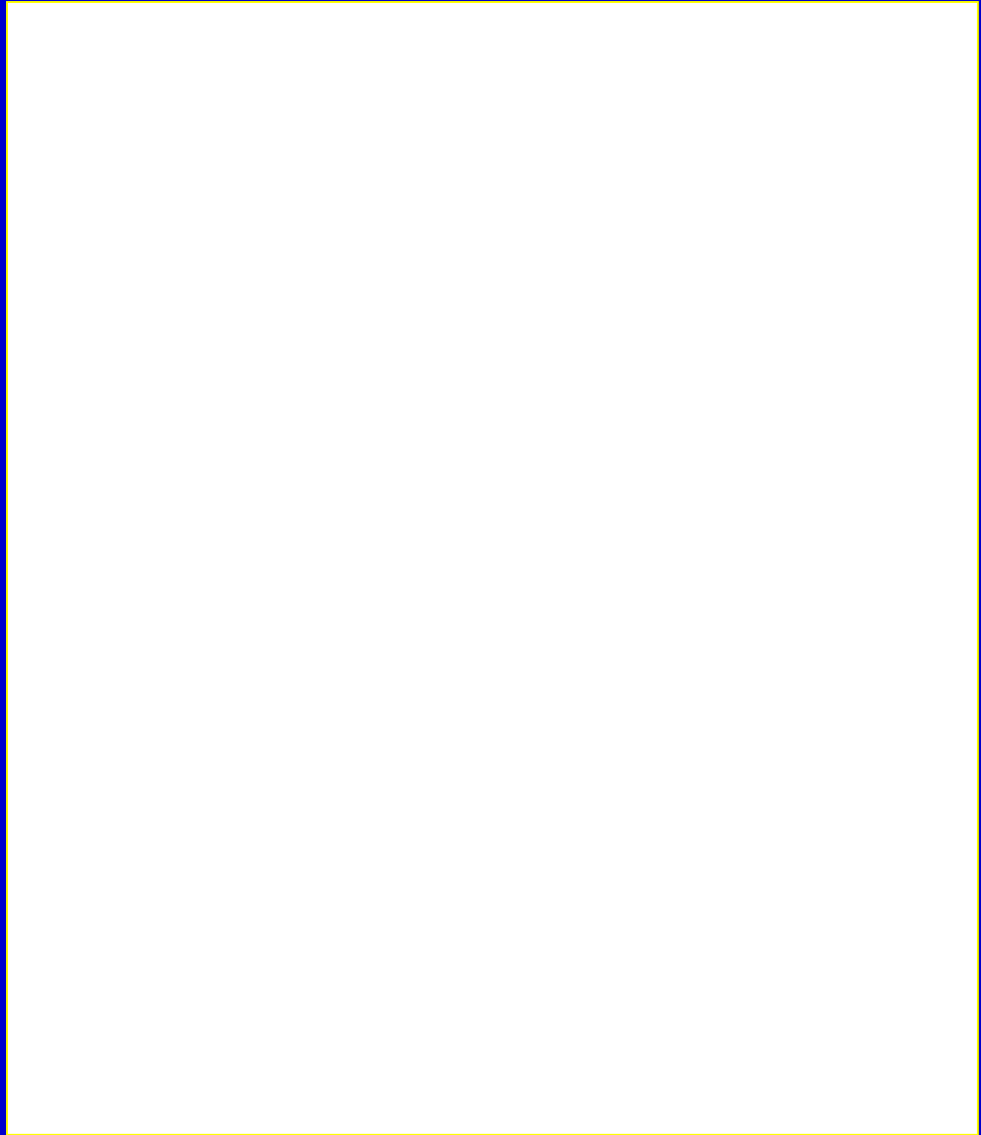
Rao et al. 1998



Magnetic Fields

see also H_2 map of Chrysostomou et al. 1994

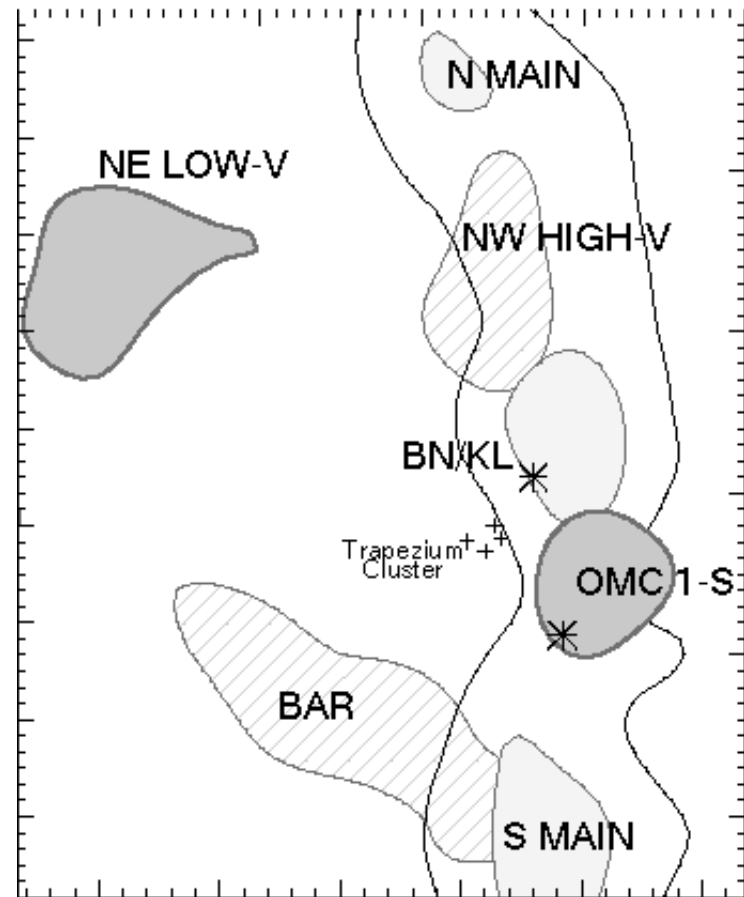
What's
the field
doing?



Magnetic Fields

Figure from: Kannappan & Goodman 1998

What's
the field
doing?



Magnetic Fields

Figure from: Kannappan & Goodman 1998

What's
the field
doing?

— HII Region

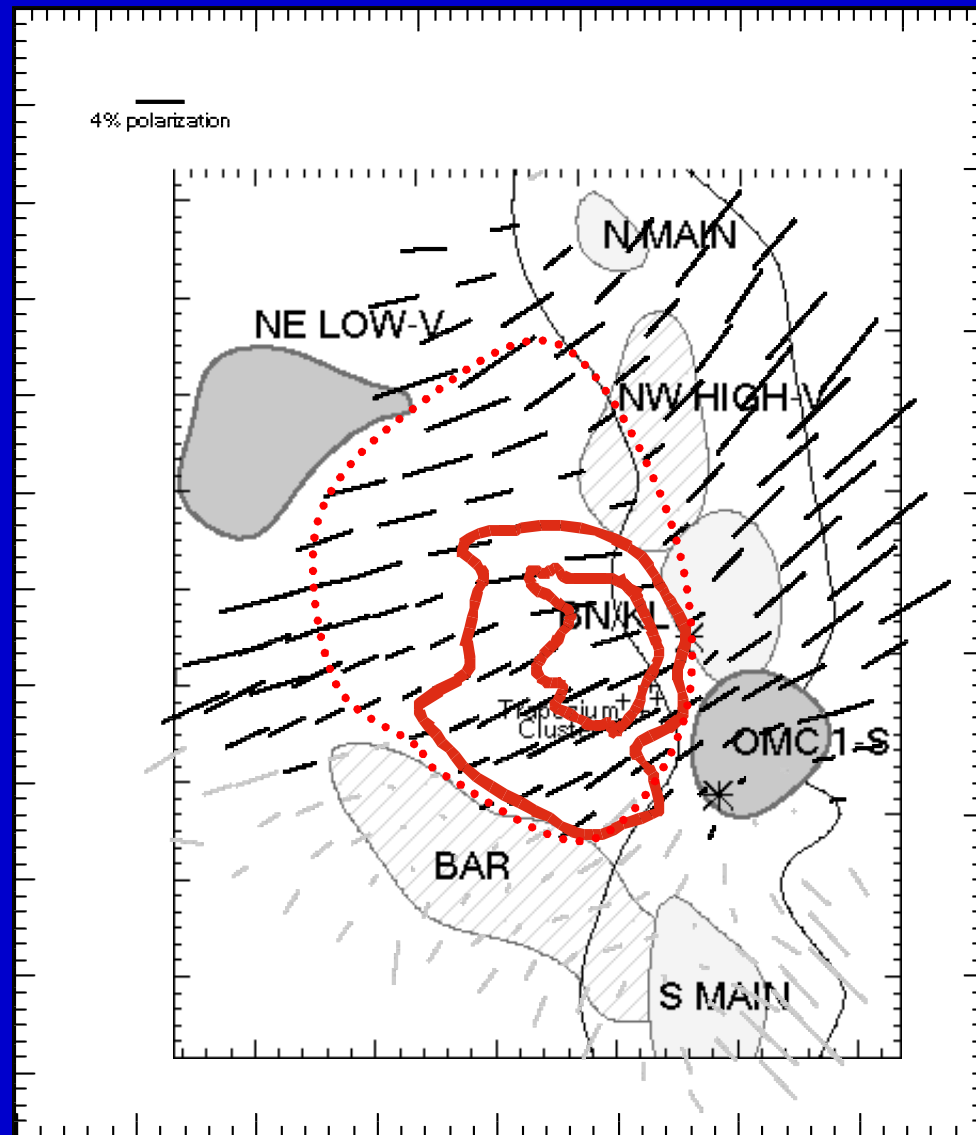
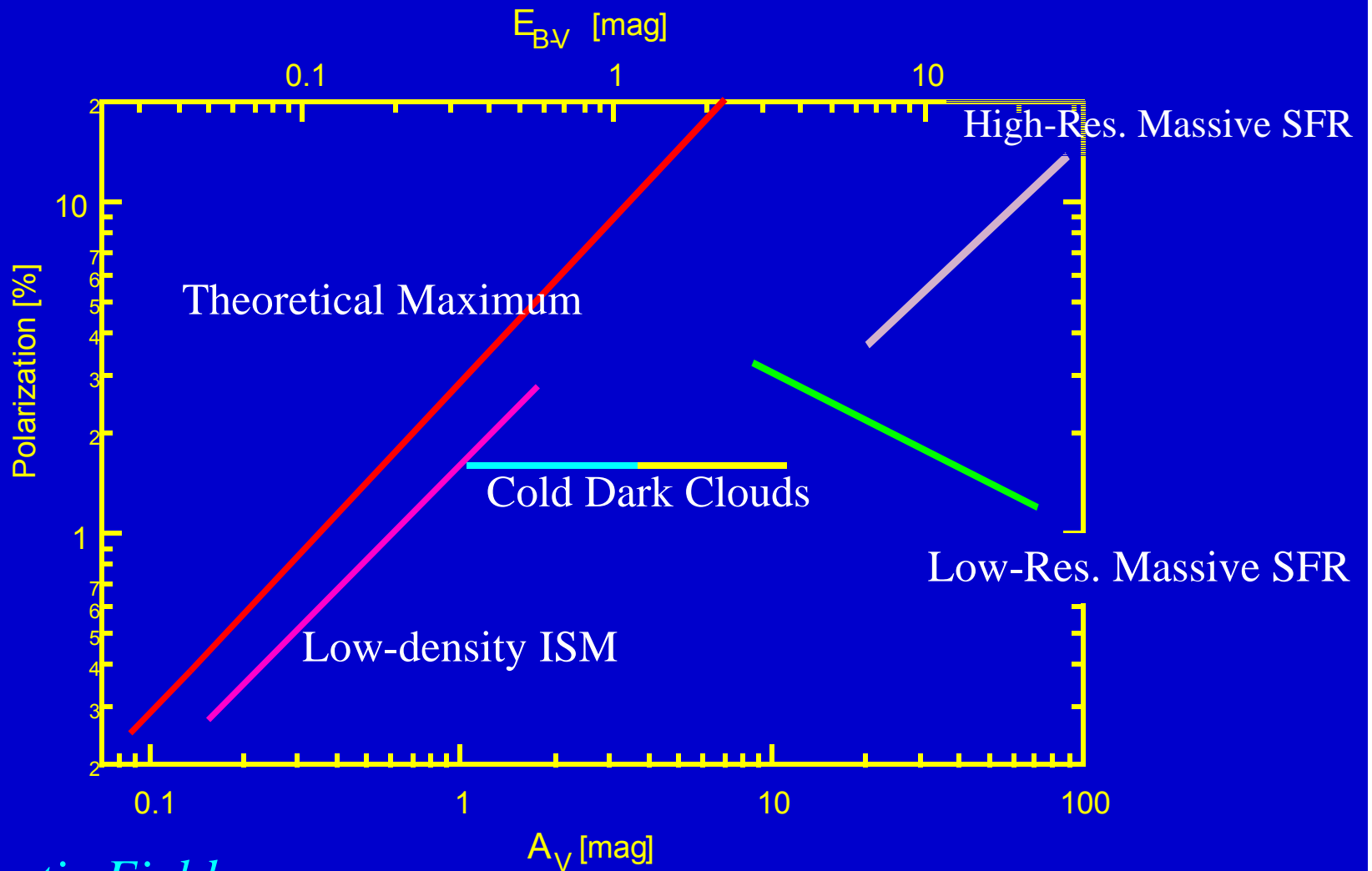


Figure from: Kannappan & Goodman 1998

Magnetic Fields

“ $p-A_V$ ” in Star-Forming Regions: *What does it mean?*



Magnetic Fields

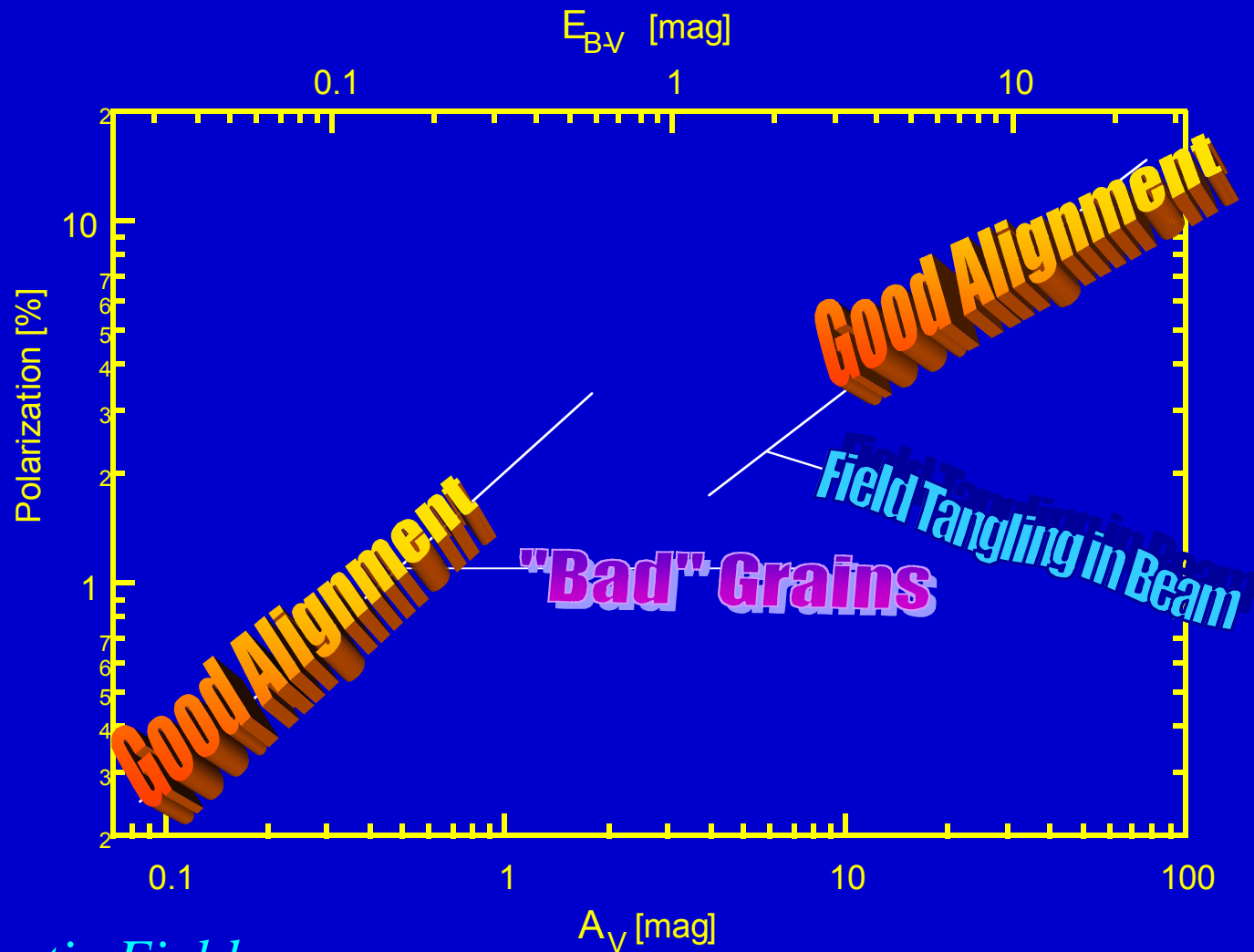
“ $p-A_V$ ” in Star-Forming Regions: *Grain Alignment Issues*

- **Dark clouds:** bad grains or poor alignment?
 - Lazarian et al. 1997 suggest poor alignment
- **Massive SFR:** good grains or better alignment?
 - temperature and/or radiative environment
- Importance of **non-Davis-Greenstein alignment mechanisms**
 - e.g. **radiative alignment** of “helical” grains (Draine & Weingartner 1997)
 - **streaming** alignment (suggested in Orion BN/KL)

Magnetic Fields

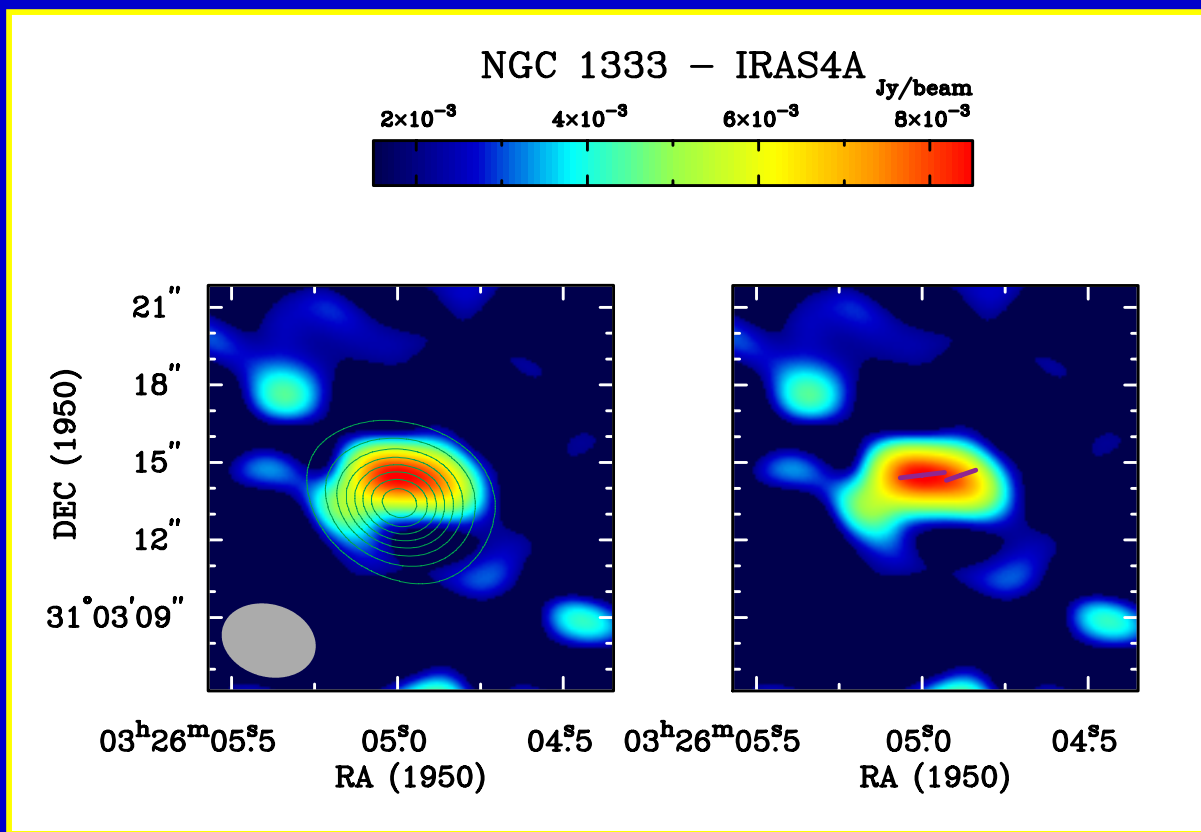
“p-A_V” in Star-Forming Regions:

What does it mean?



Magnetic Fields

Thermal Emission Polarimetry around Individual YSO's & Outflows

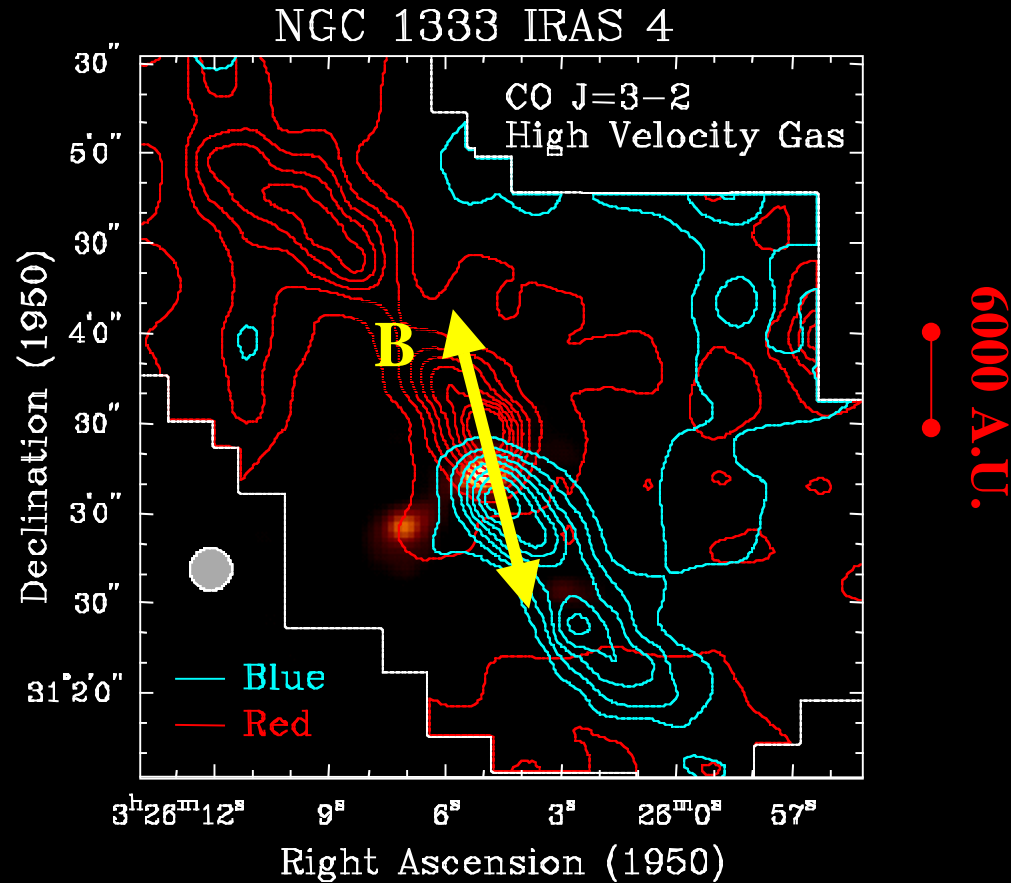


1000 A.U.

3-mm OVRO -- Akeson et al. 1996

Magnetic Fields

Outflow along the B-field? (Yes, maybe.)



What about the large
scale field?

Magnetic Fields

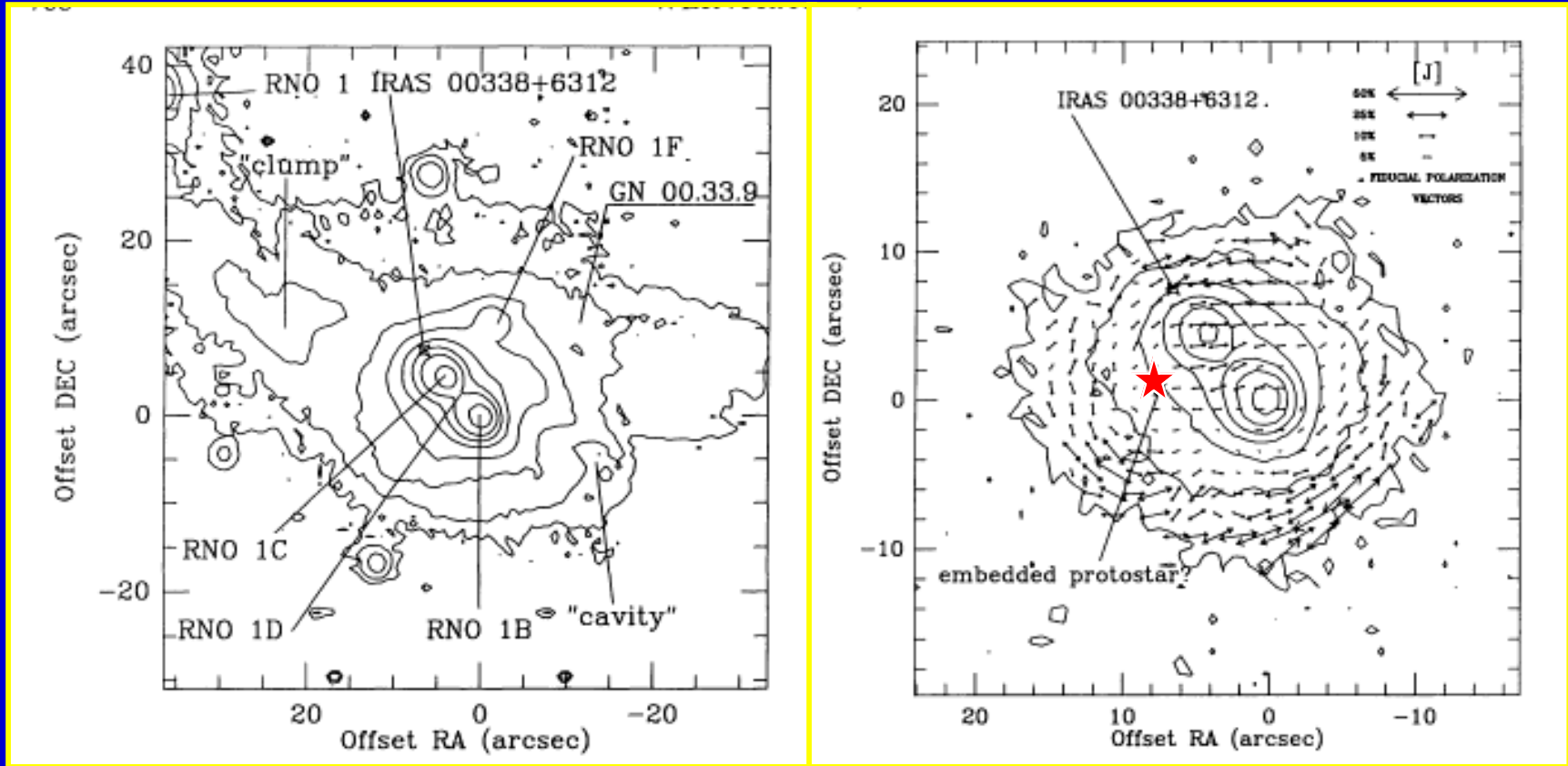
CO outflow -- Blake et al. 1995

Scattered-Light Polarimetry around Individual YSO's & Outflows

- novel way to identify **driving source**
- provides detailed tests of **density structure models**

Circumstellar Nebulae

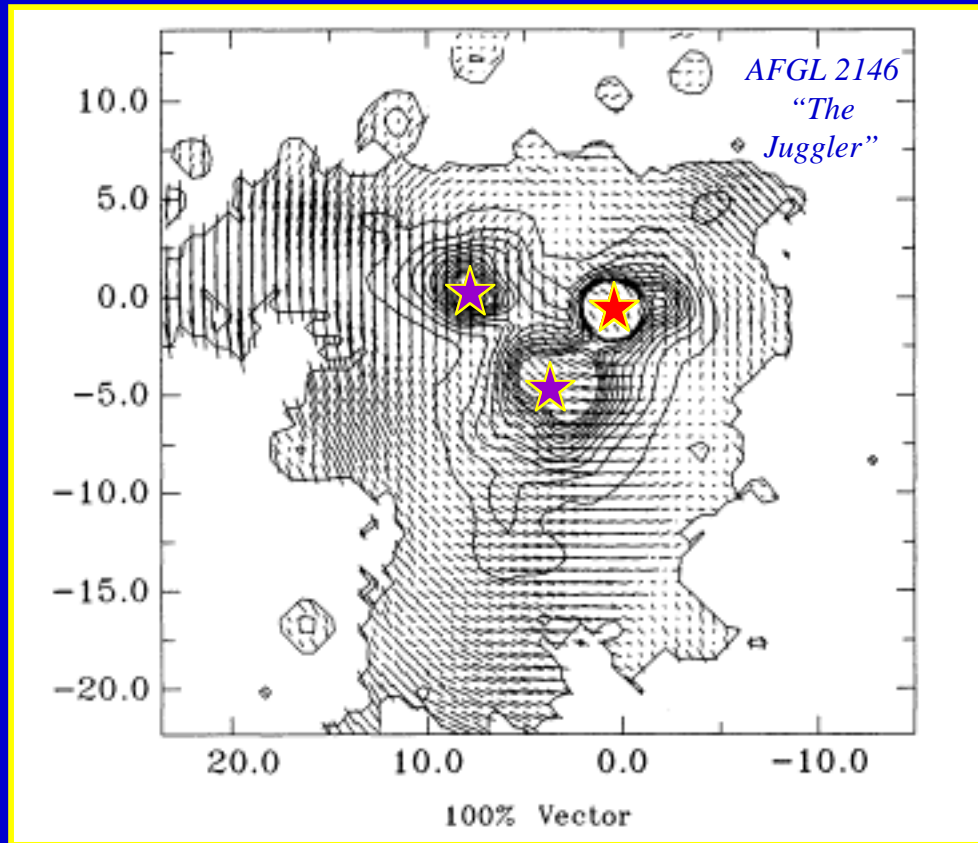
Identification of Driving Source (in L1287)



Weintraub & Kastner 1993

Circumstellar Nebulae

Will the true source please stand up?



Minchin et al. 1991

- ★ “fake” stars (scattered light peaks only)
- ★ “real” star (center of scattered-light polarization pattern)

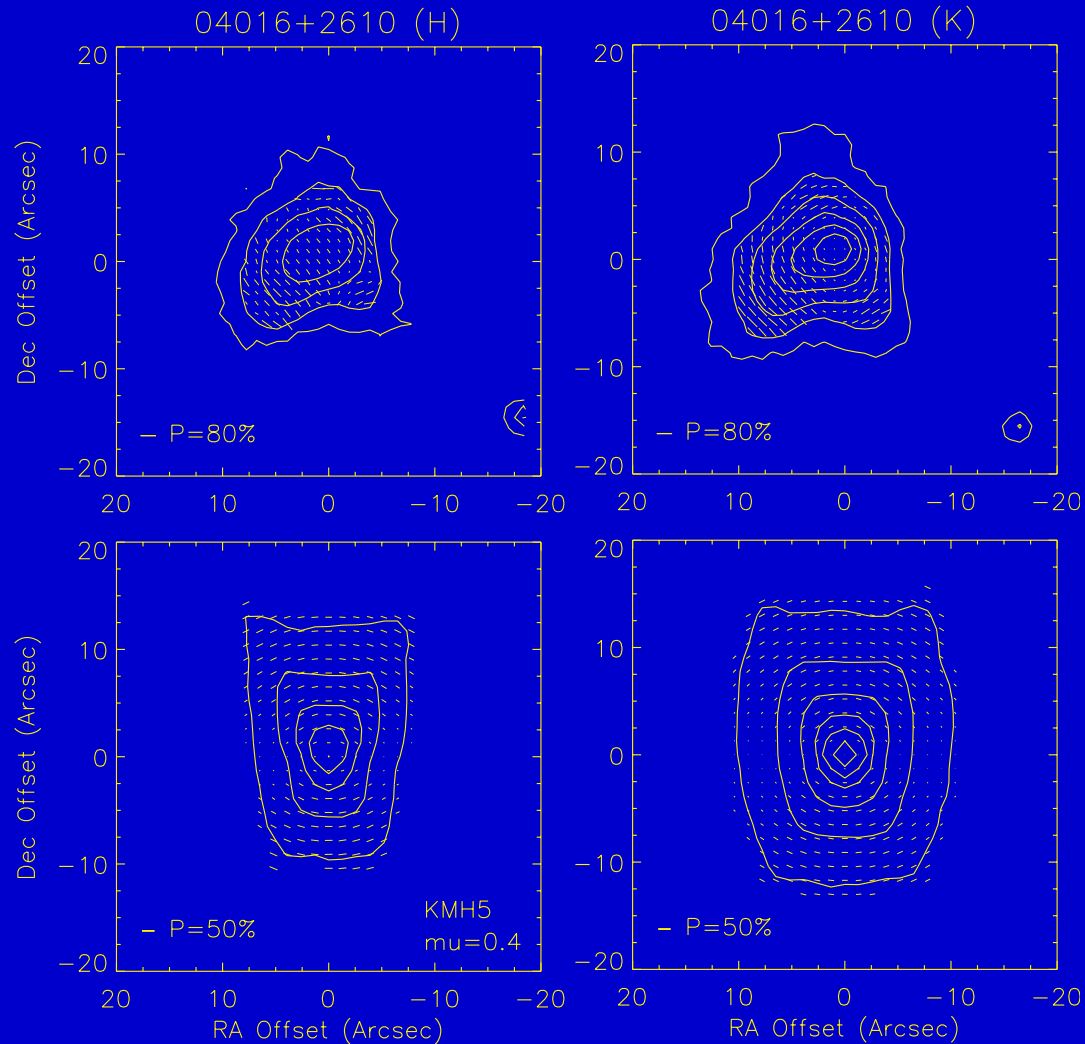
Note: This kind of map also gives disk orientation and information on outflow cavity.

Circumstellar Nebulae

Modeling Circumstellar Density Structure

Observations:
L1489 H &
K-band maps

Model:
TSC infalling
envelope;
KMH grains;
inclined 66°



Observations

Model

Circumstellar Nebulae

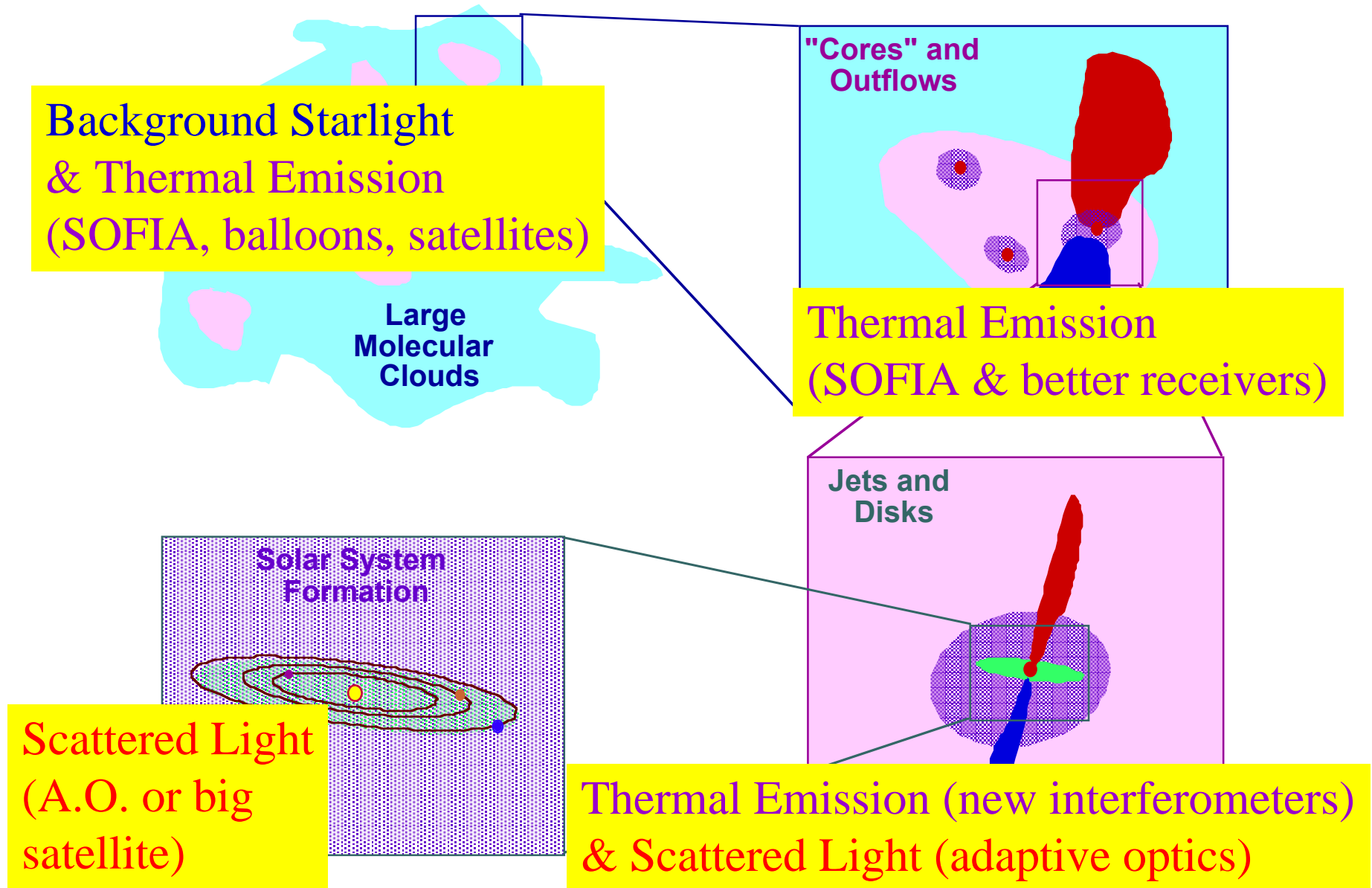
*Whitney, Kenyon
& Gómez 1997*

Grain Properties from Polarimetry

- Spectropolarimetry of ices and other features
- Observations of circular polarization
- Theoretical modeling
 - matching $A(\lambda)$ and $p(\lambda)$ curves to get grain size distribution
 - alignment theories

Combination provides much information on grain size, shape, and composition distributions.

PPV: What's good where (then)?

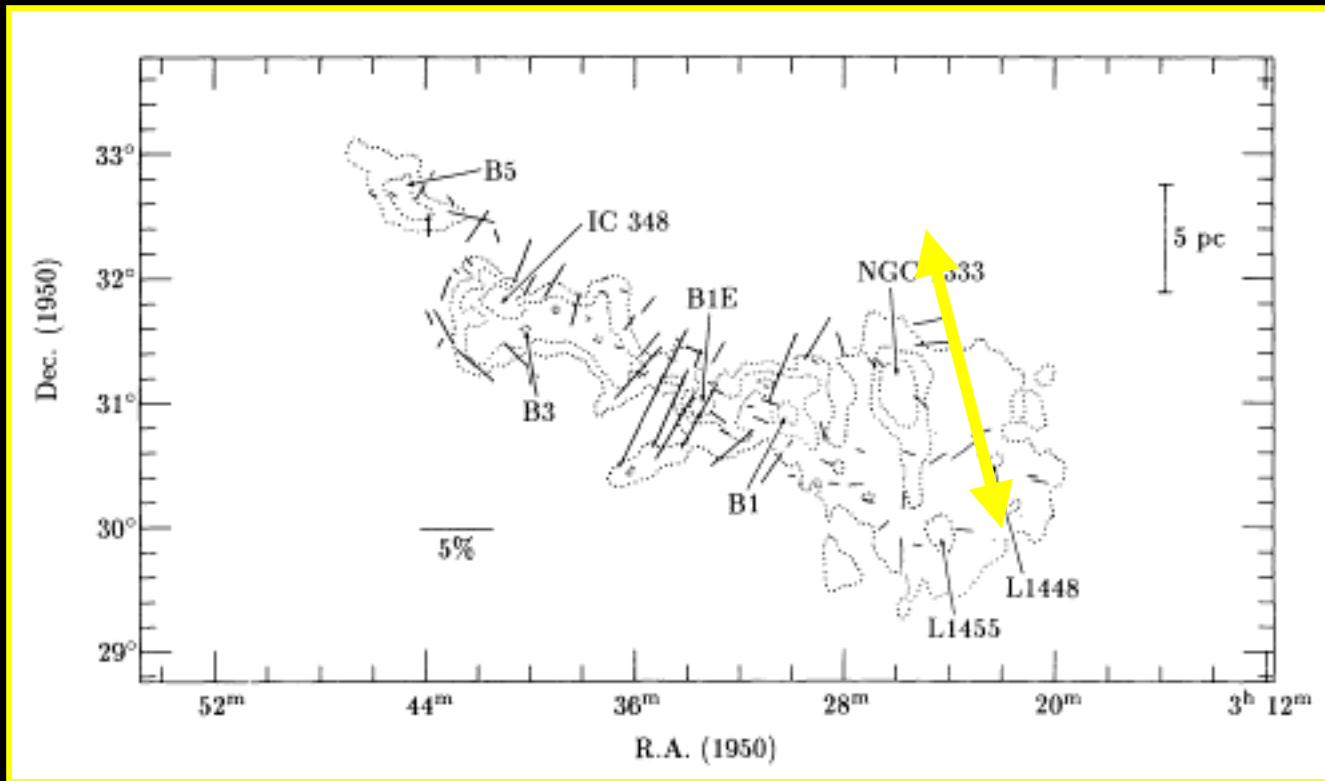


Protostars & Planets V

- Background Starlight Polarimetry (including spectropolarimetry)
 - dust properties
- Thermal Emission Polarimetry
 - airborne, balloon, and satellite observations plus interferometric observations at mm, sub-mm, far-IR
 - (finally!) understand how the field gets from the ISM to a protostar
- Scattered-light Polarimetry
 - facility instruments & adaptive optics, work at near-IR
 - “circum-binary/circum-cluster” density structure

The Future

Relation to the Large-Scale field

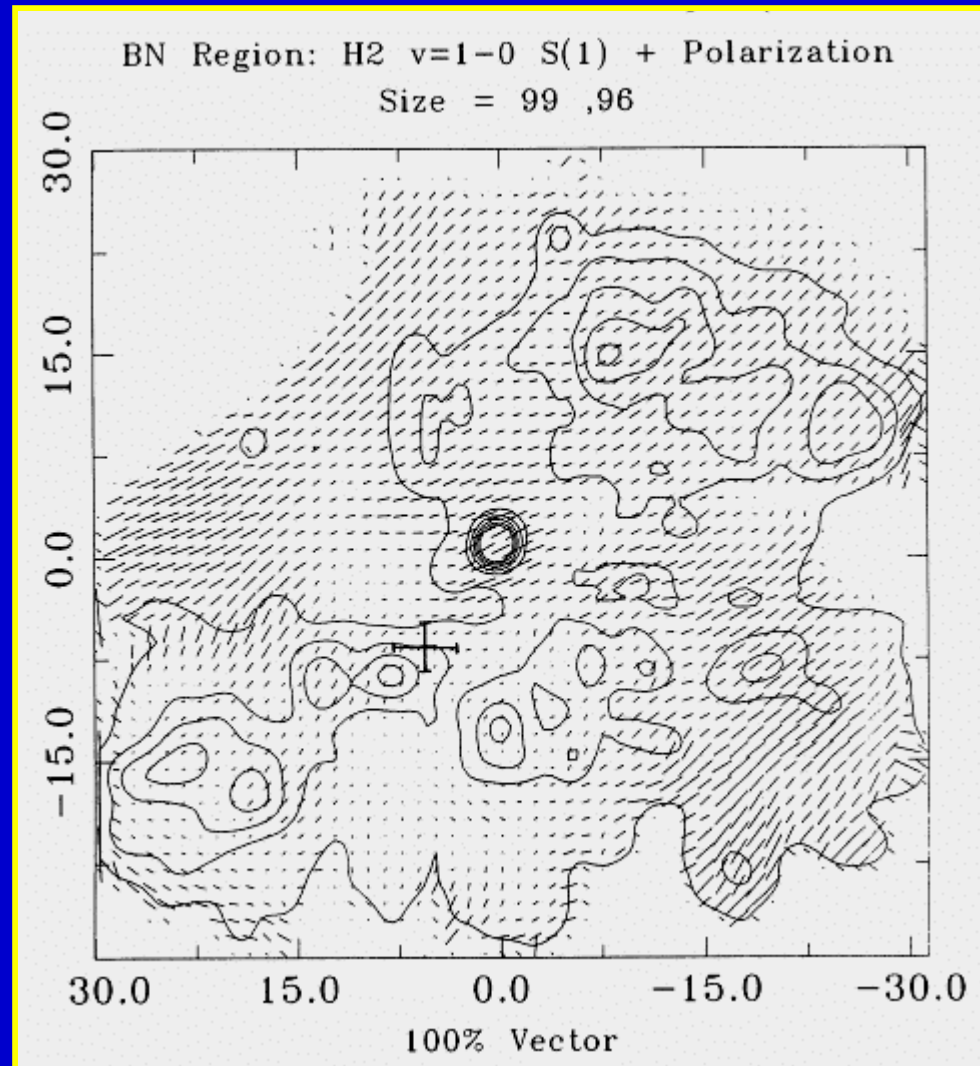


How about the small-scale field?

Goodman et al. 1990

Magnetic Fields

Massive Star-Forming Regions: Orion

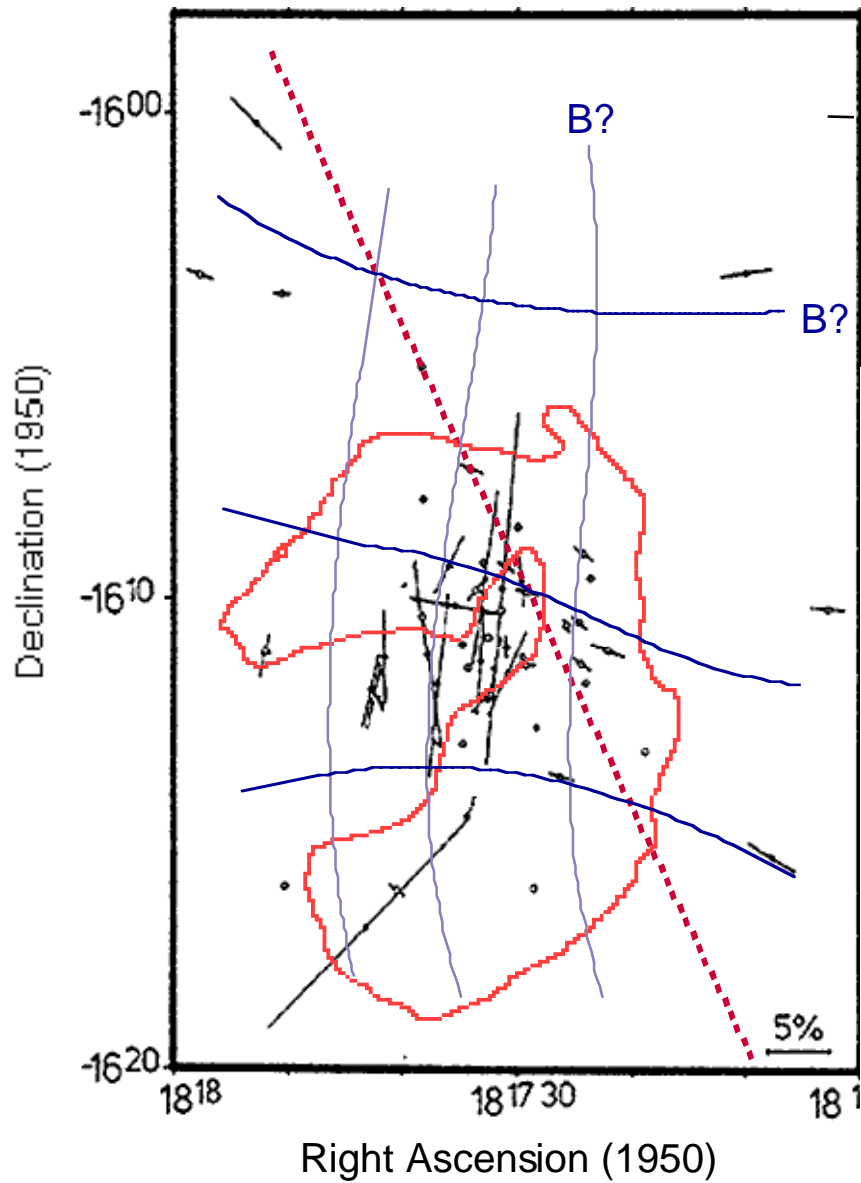


Polarization
in H₂ filter

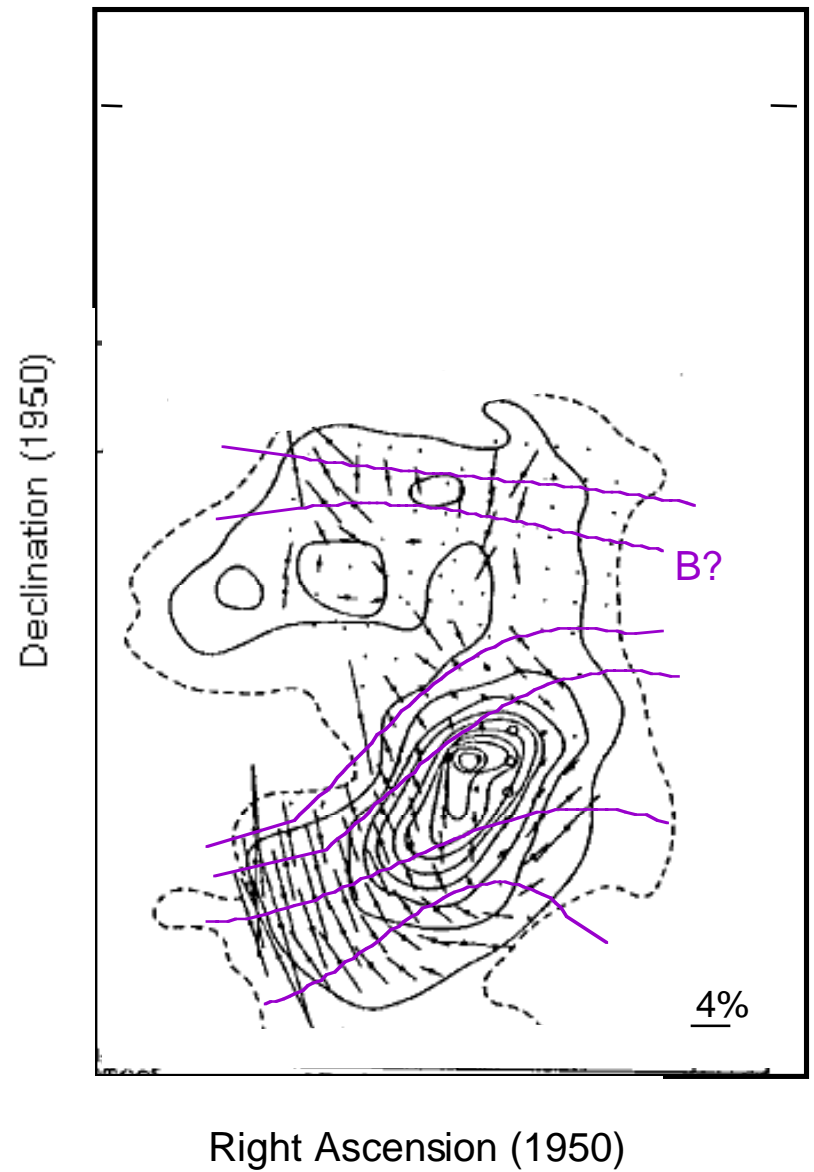
Magnetic Fields

Chrysostomou et al. 1994

Polarization of Background Starlight in M17
Schulz et al. 1981



Polarization of 100 mm Emission in M17
Dotson 1995



M17