Using the Faraday Effect to Probe Magnetic Fields in HII regions

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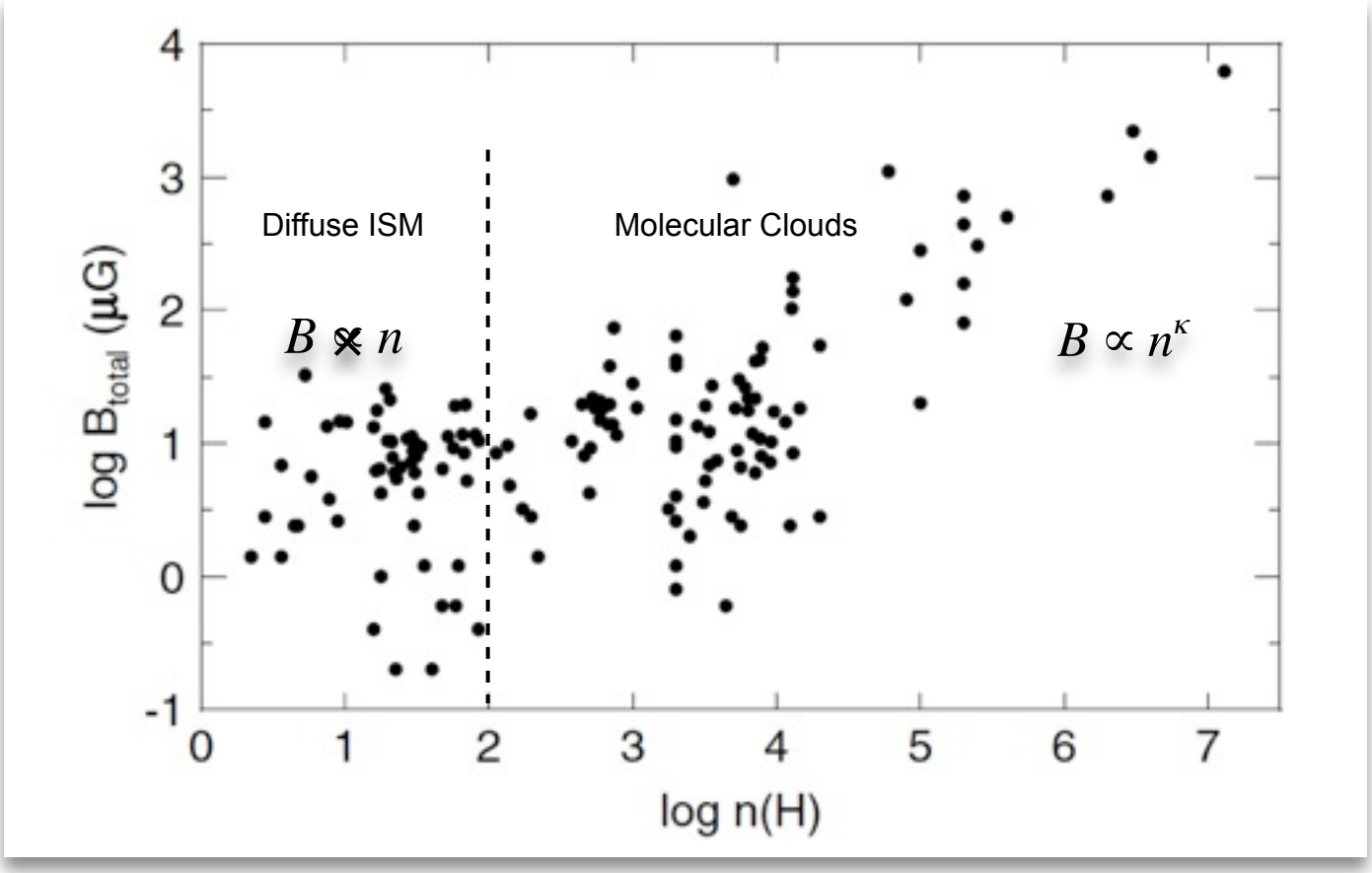
Cosmic Magnetism - From Stellar to Intergalactic Scales
Southern Cross Astrophysics Conference Series, Kiama, NSW

THE UNIVERSITY OF SYDNEY

The Big Issues

- Star formation relies on the accumulation of very diffuse material from large volumes.
- What is the role of magnetism in star-formation?



Crutcher (2008)

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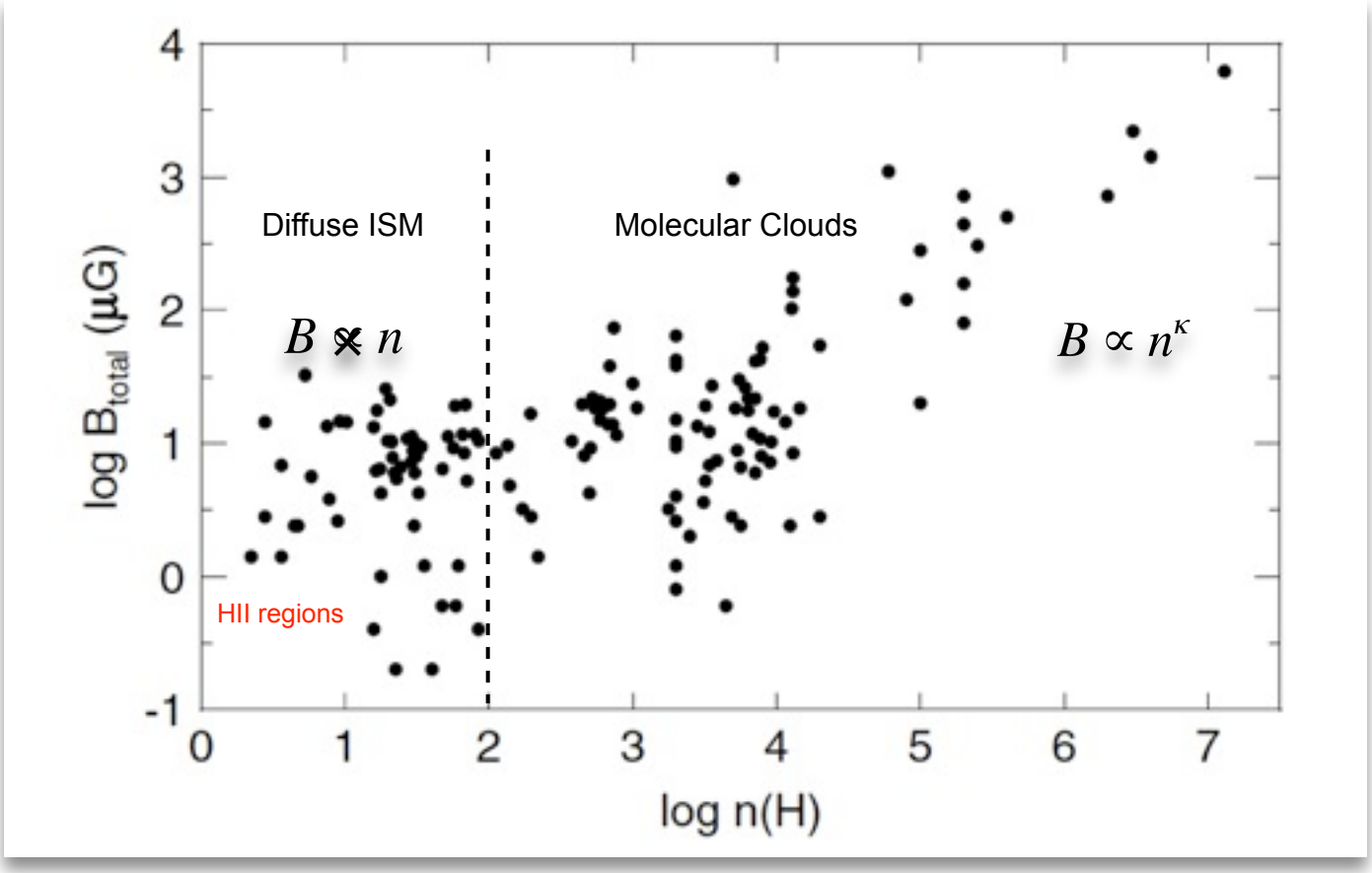


Crutcher (2008)

Background

Questions:

- What is the magnetic field strength in HII regions?
- How does magnetic field strength scale with density in the diffuse ISM?
- What is the scale of magnetic field reversals in HII regions?

Previous Work:

- RRLs and HI/OH Zeeman effect can yield $B_{||}$ in much denser material close to periphery of HII regions, (e.g. Bloemhof et al. 1992; Roshi et al. 2007).
- Only a handful of measurements been made of magnetic field strengths *within* HII regions (Heiles et al. 1980, 1981) in the 1-10 cm^{-3} material.
- Recent improvements in Hα and radio polarization data allow an in-depth study of $B_{||}$ in HII regions.

Methodology:

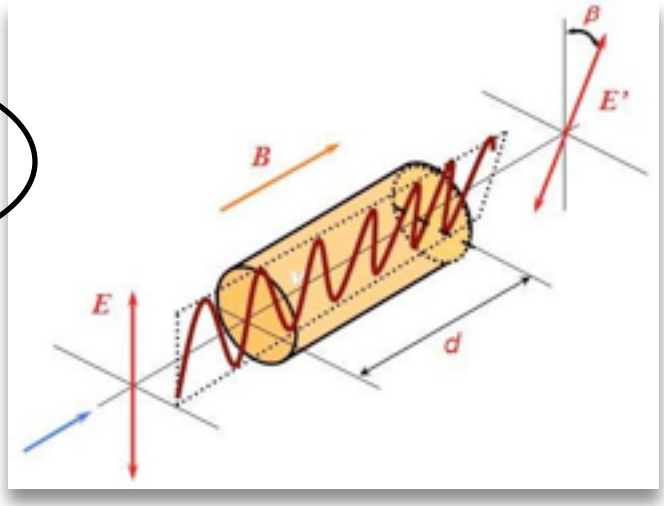
- We use measurements of the Faraday effect on *linearly polarized radio waves* from *distant galaxies* to estimate the magnetic field strength in 5 Galactic HII regions.
- Examine B vs. n relation for 5 HII regions over a factor of 20 change in density.

The Faraday Effect

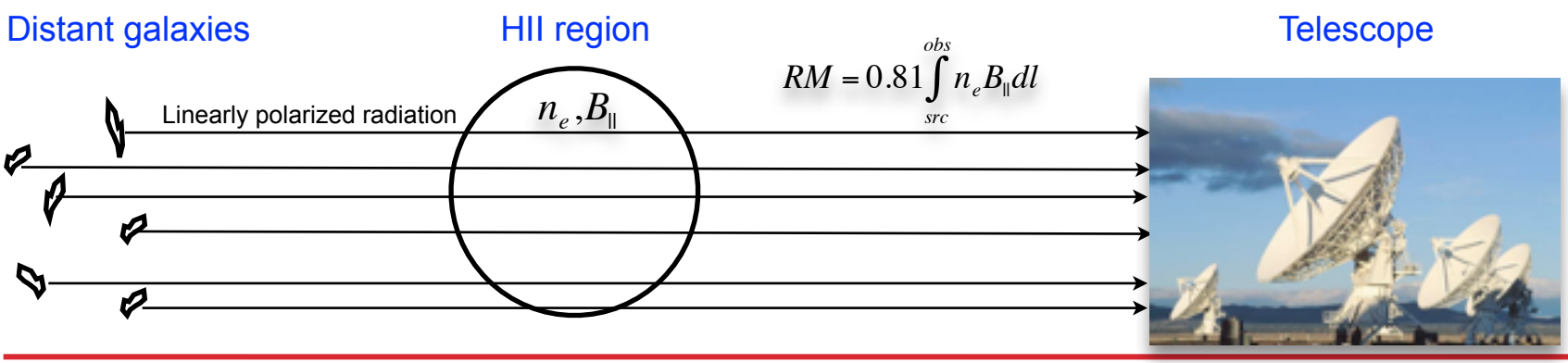
› **Faraday effect**: Change in polarization angle in a magneto-ionic medium due to circular birefringence (LCP and RCP having different speeds).

I'll wager £20 that

$$\Delta\chi = RM\lambda^2$$



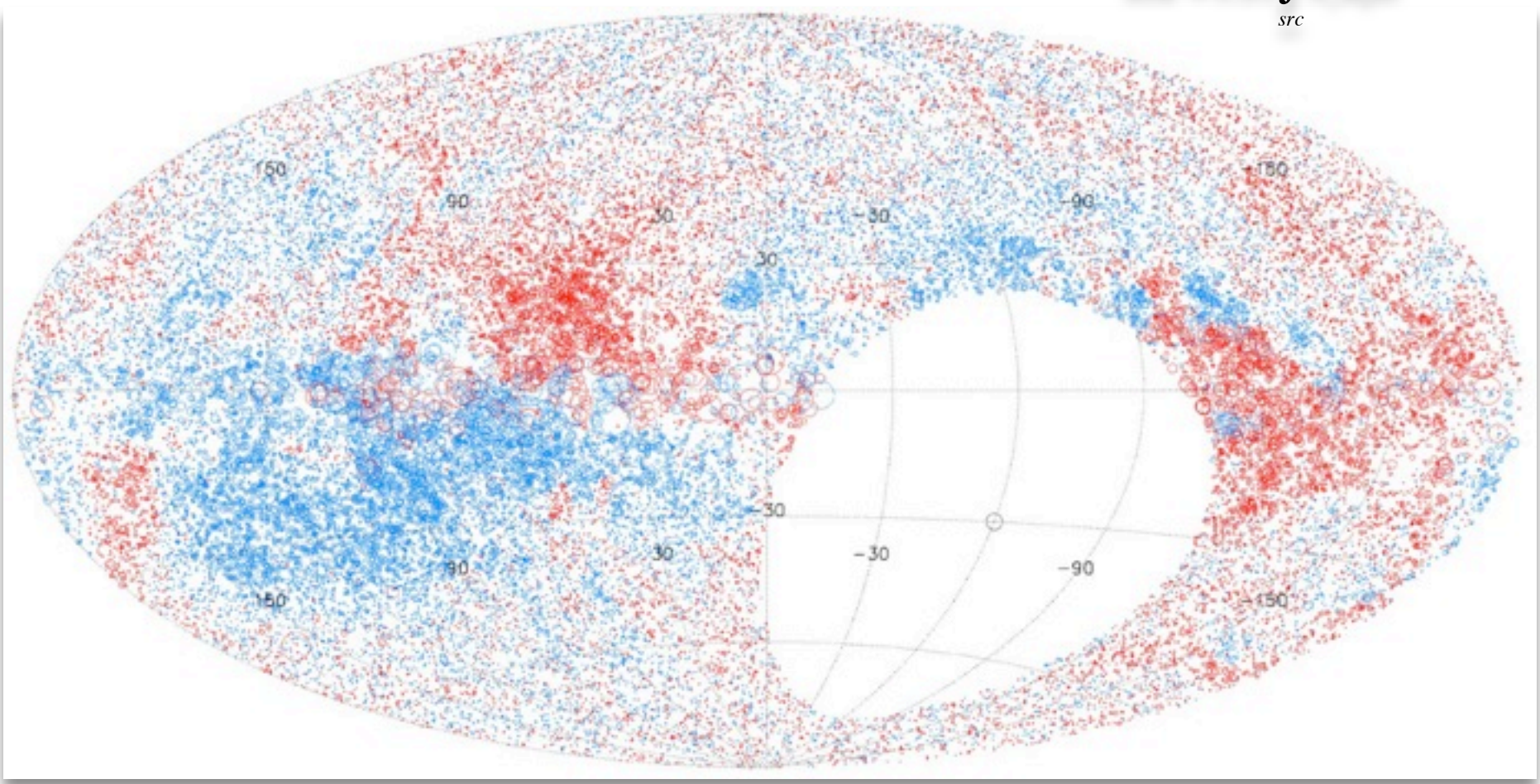
Astrophysical Measurement of the Faraday Effect



A Rotation Measure Image of the Sky

Image: NVSS rotation measure catalogue, (Taylor, Stil & Sunstrum, 2009)

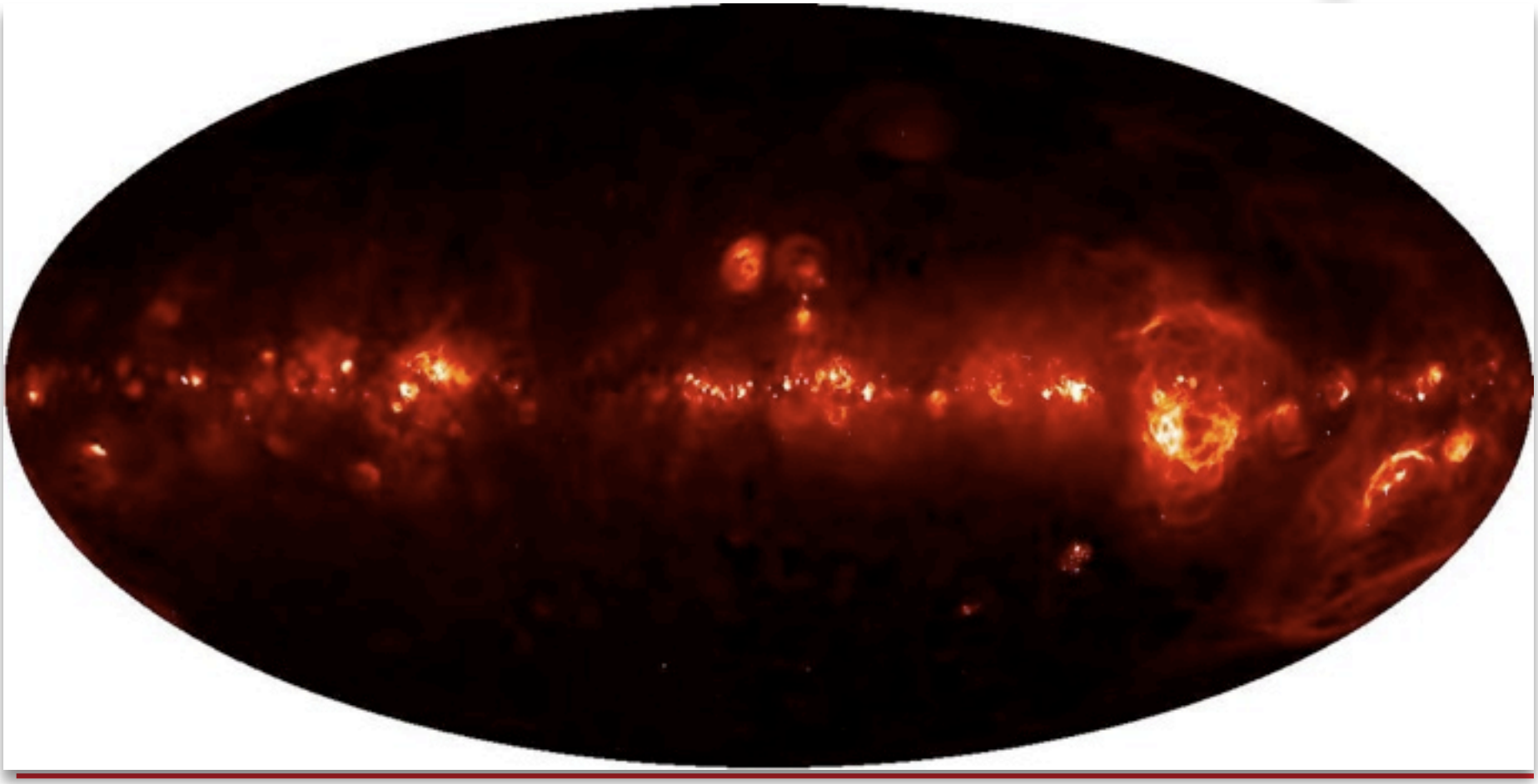
$$RM = 0.81 \int_{src}^{obs} n_e B_{\parallel} dl$$



Hα Image of the Sky

Image: Hα all sky map, Finkbeiner (2003)

$I_{H\alpha} \propto$ Emission Measure, $EM = \int_{obs}^{\infty} n_e^{\,2} dl$



Calculating n_0 and $B_{||}$

Model:

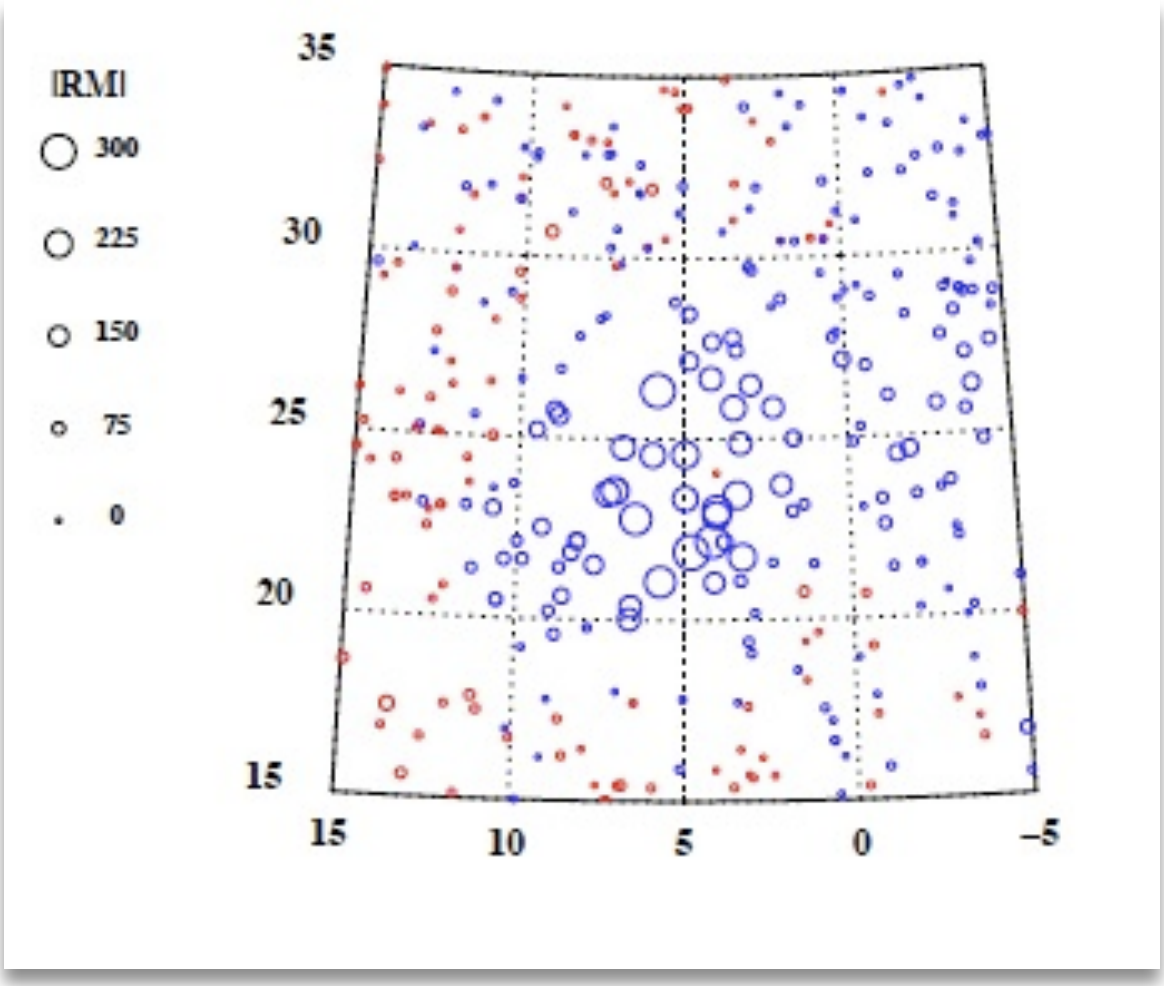
› If an HII region is clumpy, with clumps $n_e = n_0$ and elsewhere $n_e = 0$, then:

$$n_0 = \sqrt{\frac{EM}{fL}} \qquad B_{||} = \frac{RM}{0.81 n_0 fL}$$

- *f* = filling factor, *L* = path length through HII region
- Other considerations: optical extinction, RM and EM due to back/foreground.

- Given a model for the HII region and filling factor, can determine n_0 and $B_{||}$ at each position where we have an RM.
- Use a back/foreground correction to isolate the *in situ* magnetic field.
- Choose regions outside Galactic plane (dust extinction).

Sharpless 2-27



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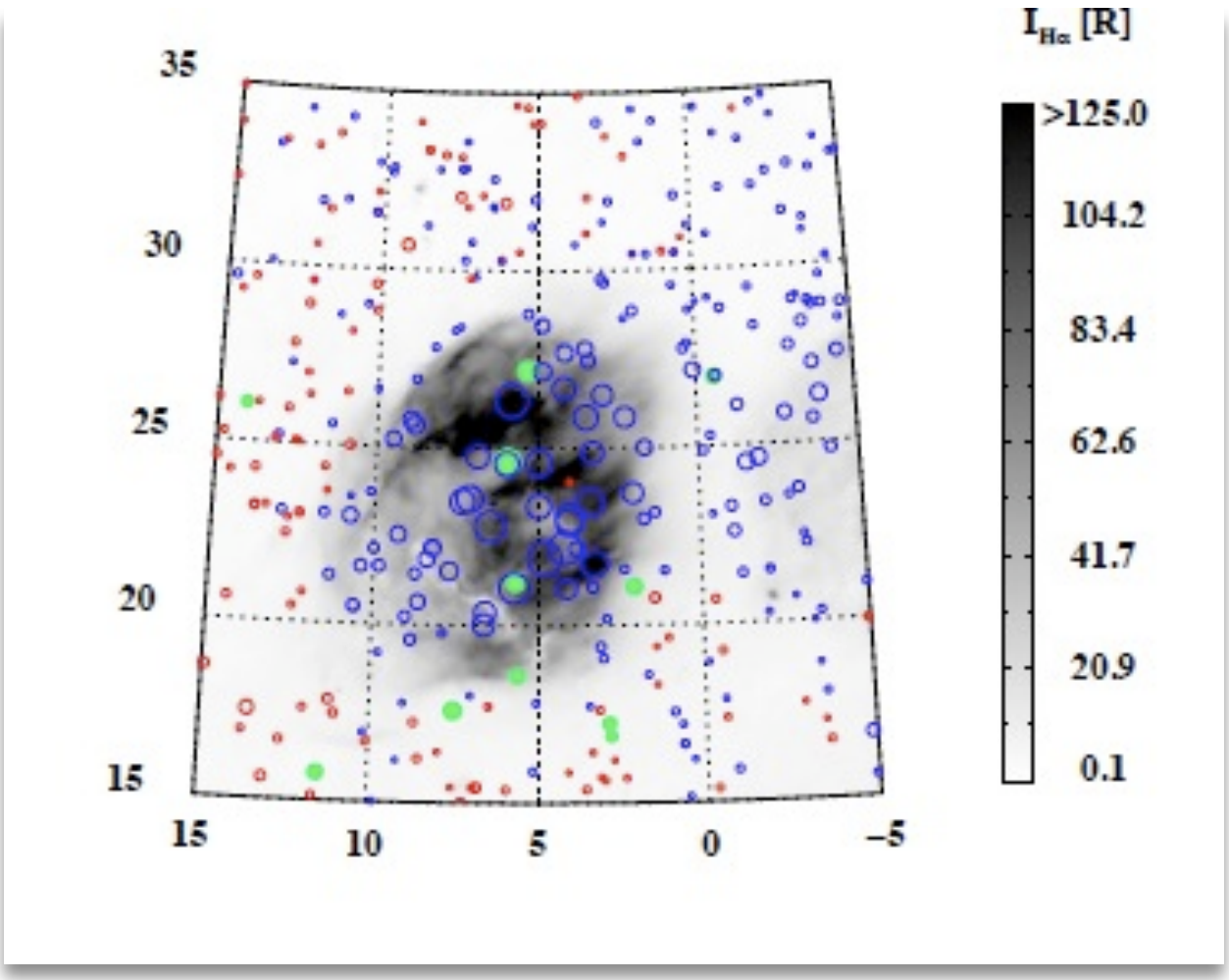

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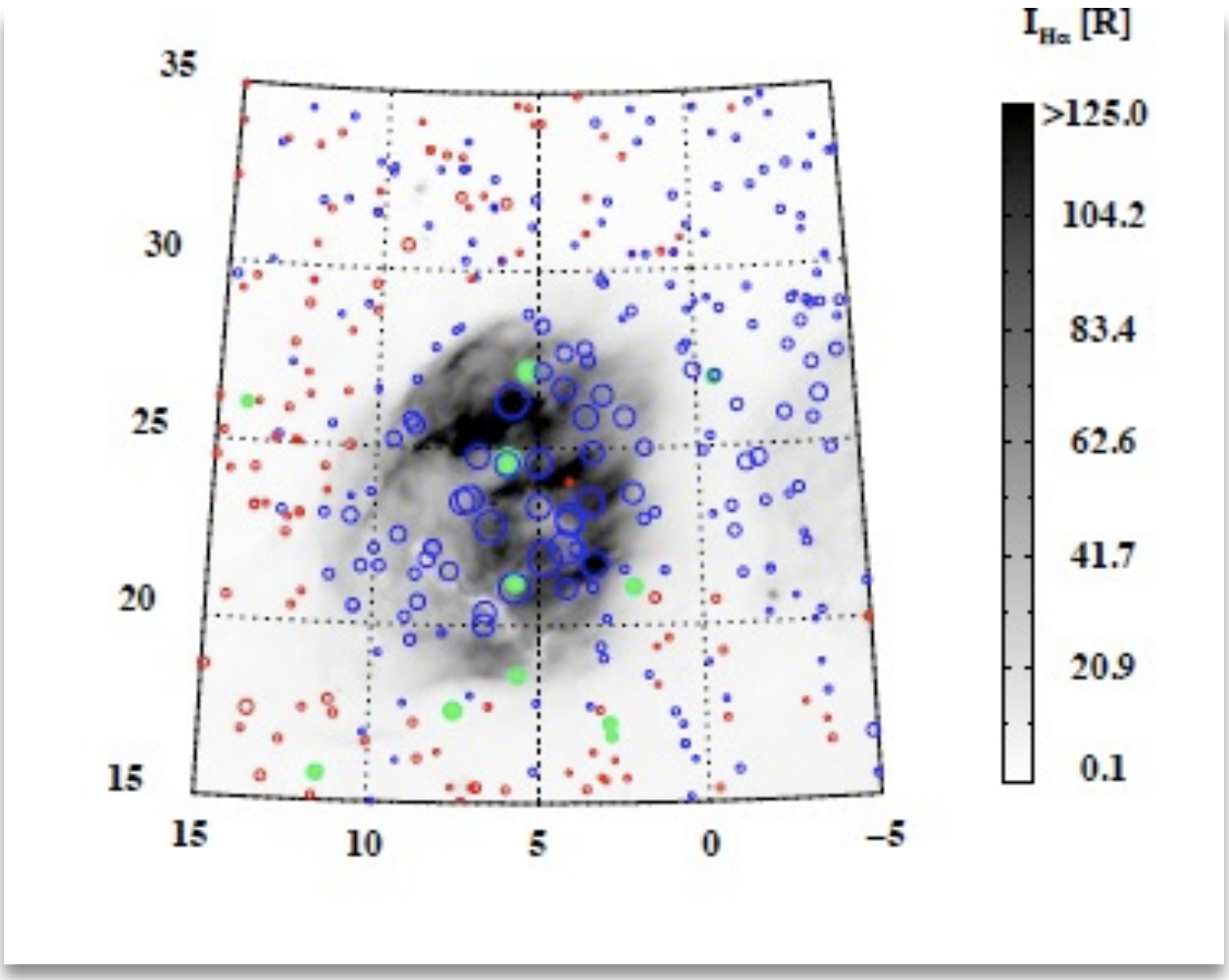
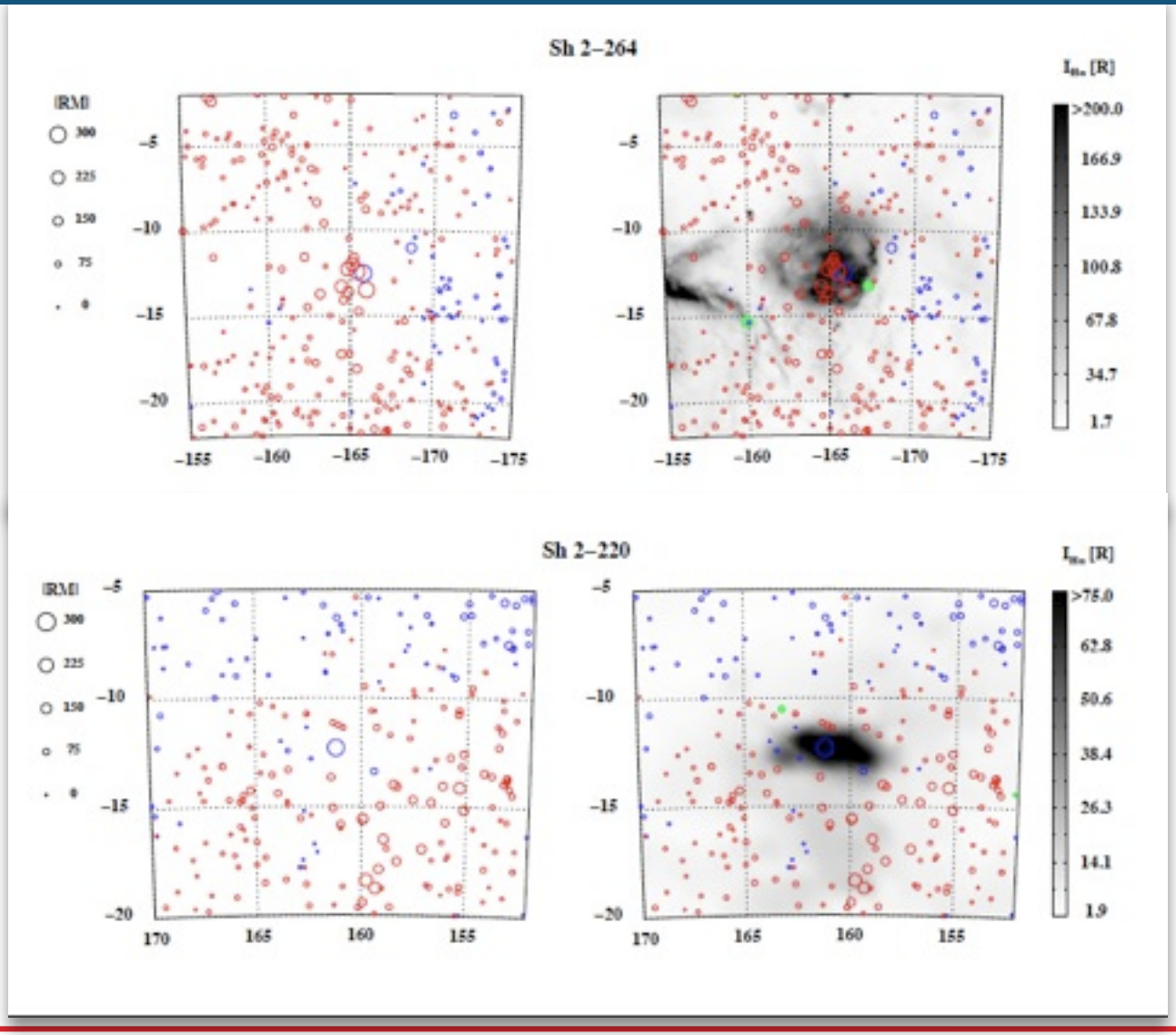


The HII Regions



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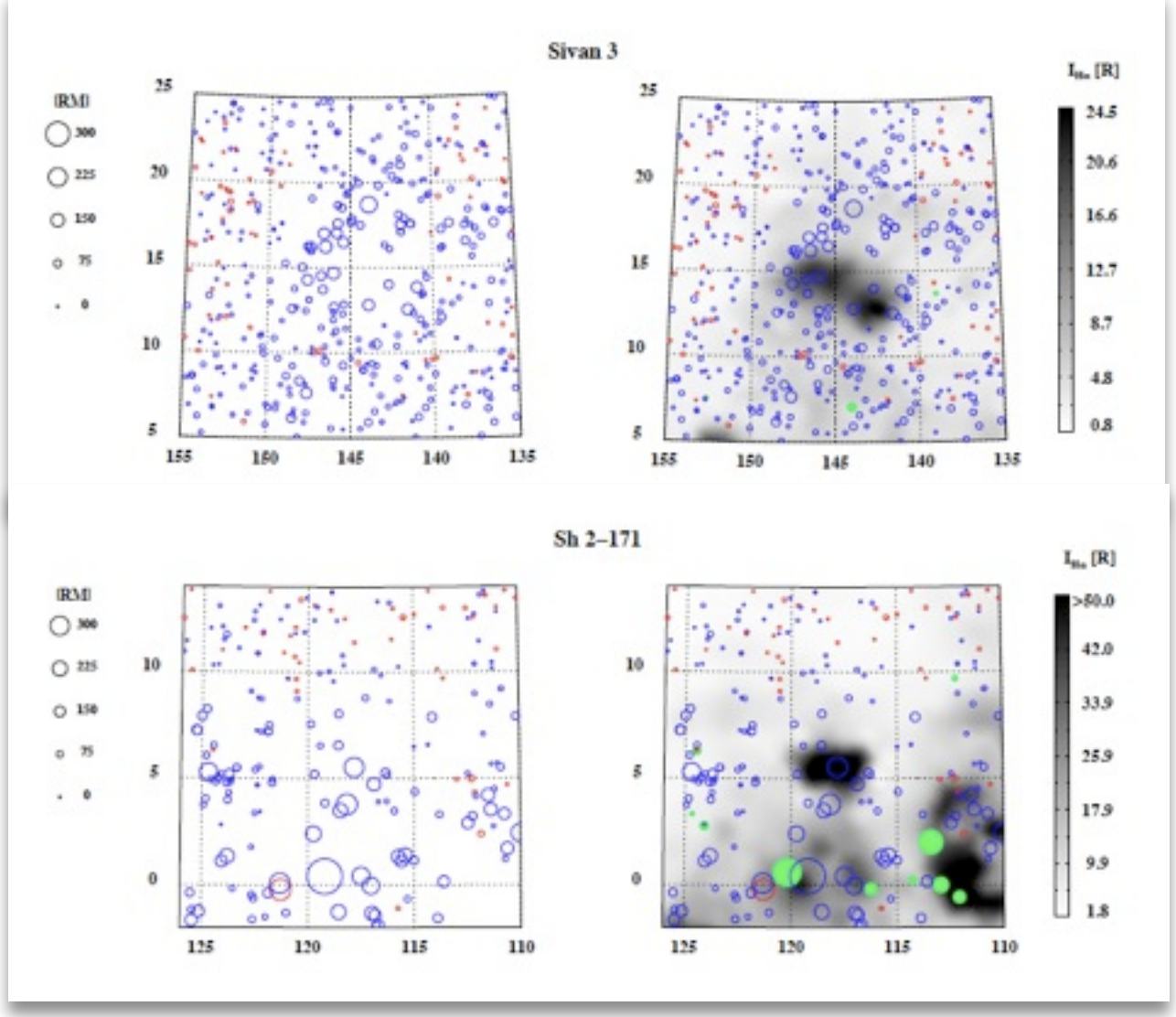
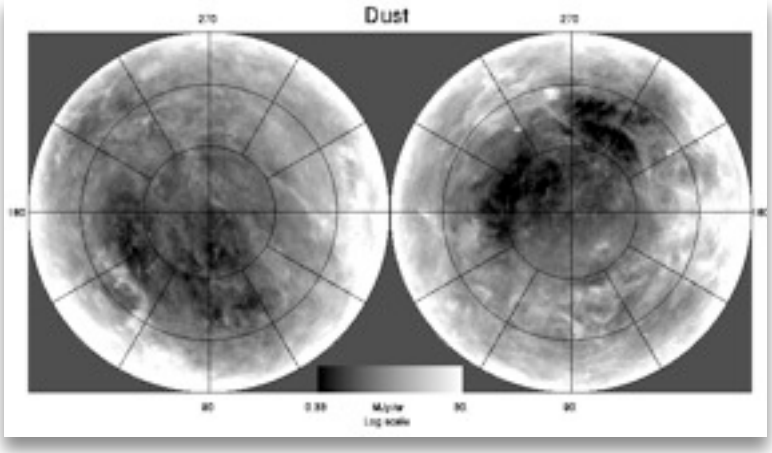


Method

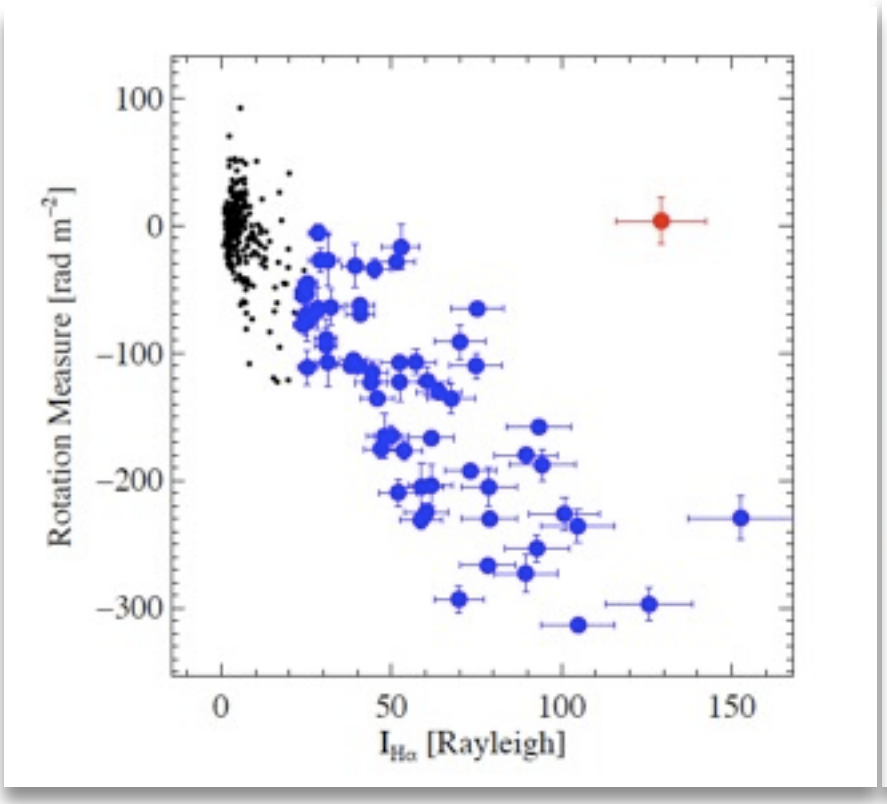
1. Define boundary of HII region
2. *Inside boundary:* For each RM position, calculate the EM from $I_{H\alpha}$
3. Correct each EM for extinction by interstellar dust (assume dust in front)
4. *Outside boundary:* Calculate the RM and EM not due to the HII region and subtract from data within the boundary.
5. Calculate $B_{||}$ and n_0 for each sightline.
6. Plot $B_{||}$ vs. n_0 for each HII region.

$$B_{||} = \frac{RM}{0.81 n_0 f L} \qquad n_0 = \sqrt{\frac{EM}{fL}}$$

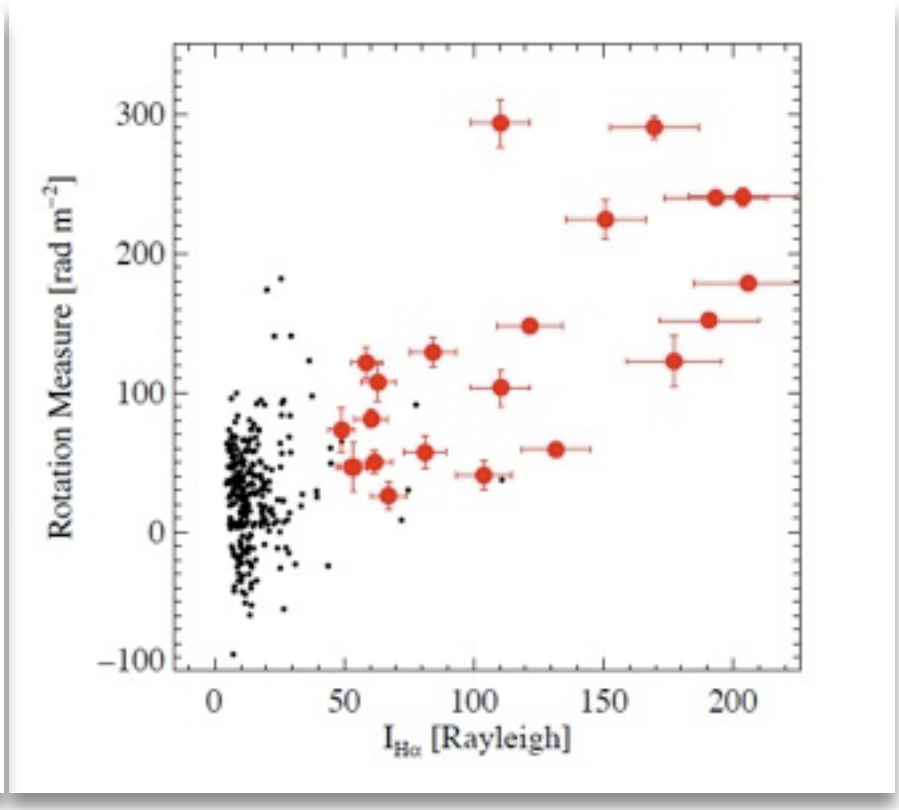


All-sky E_{B-V} map (Schlegel, Finkbeiner & Davis 1998)

Results



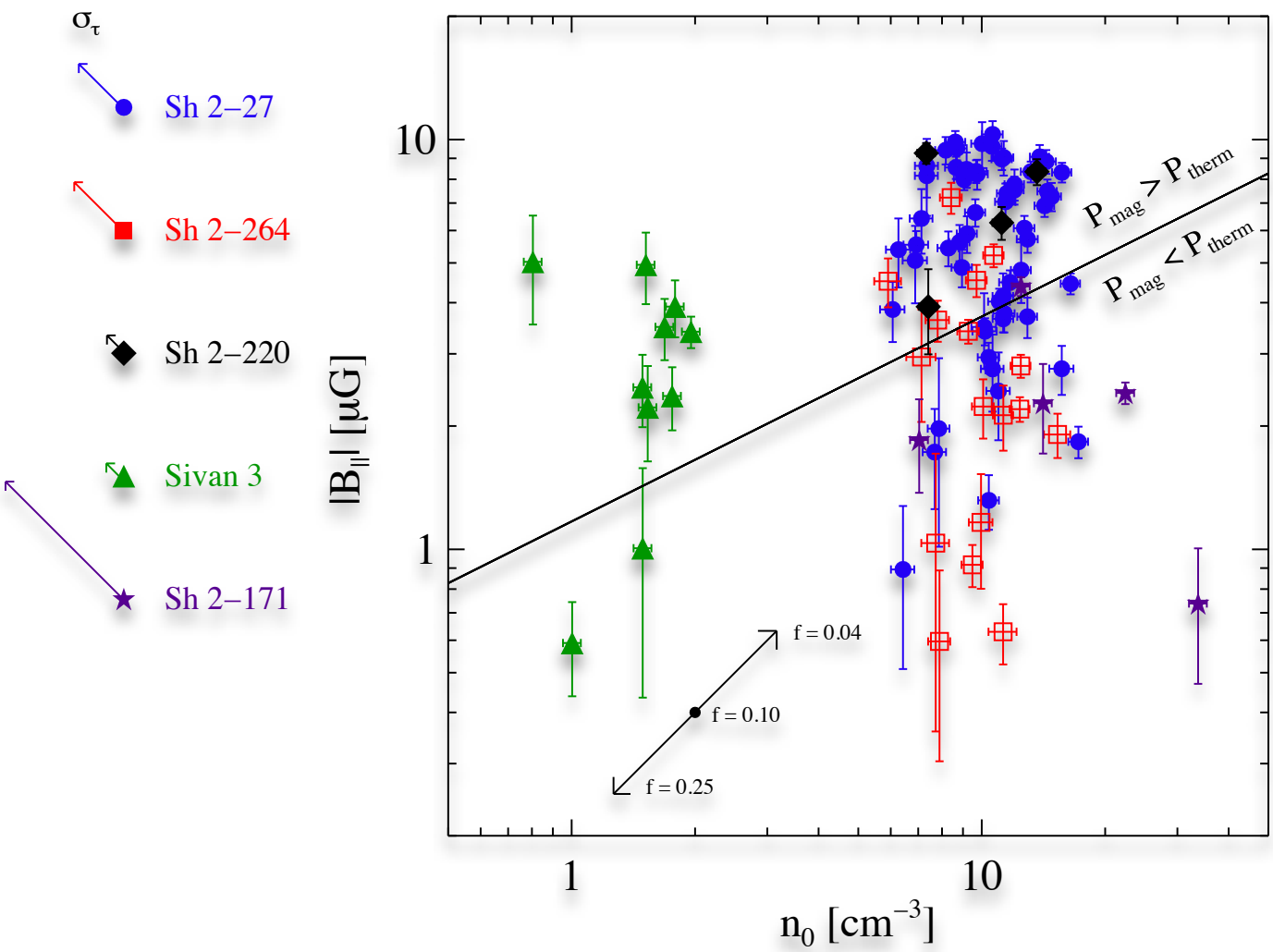
Sh 2-27



Sh 2-264

Correlation implies *in situ* magnetic field

Results: $B_{||}$ vs. n_0



Filled symbols: B > 0
Open symbols: B < 0

$$B = \sqrt{16\pi n_0 kT}$$

$$P_{magnetic} \approx P_{thermal}$$

$$B_{||} = \frac{1}{\sqrt{6}} B_{total}$$

Order of magnitude increase in n_0, very little increase in B.

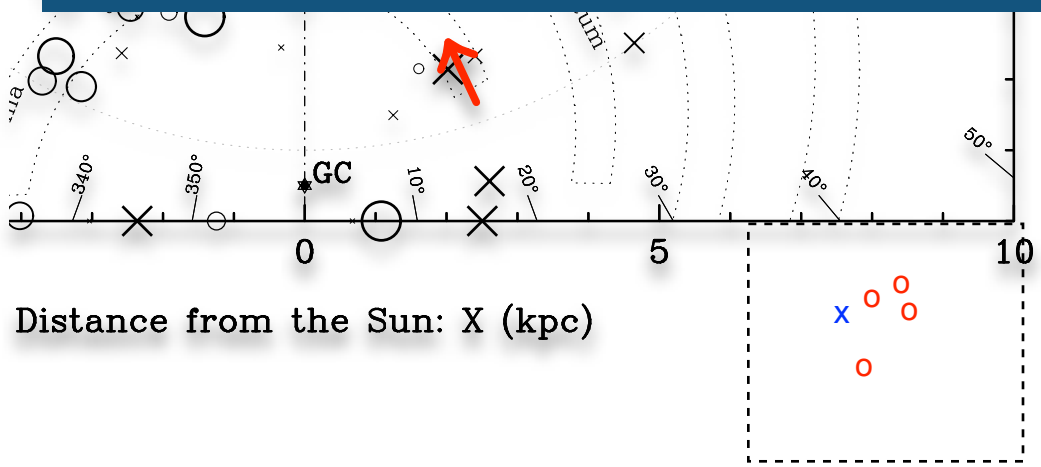
Enhanced RM in HII regions due to increased electron density.

Uncertainties:
Filling factor, f of each sight-line unknown.
Dust correction assumes all dust is in front of HII region.

Results: Derived Parameters

HII Region	R_{max} (pc)	n_0 (cm^{-3})	$B_{\|\|}$ (μG)
Sh 2-27	15	10.7 (2.7)	- 6.1 (2.6)
Sh 2-264	25	9.8 (2.3)	+ 2.8 (1.8)
Sh 2-220	20	9.9 (3.1)	- 6.9 (2.4)
Sivan 3	40	1.5 (0.4)	- 2.9 (1.5)
Sh 2-171	30	17.9 (10.4)	- 2.3 (1.3)

Magnetic Field in the Local Galaxy



Magnetic field structure of Milky Way derived from pulsars. Han & Zhang (2008)

Summary

- HII regions have magnetic fields with $B_{||} \approx 5$ μG (diffuse ISM).
- Characteristic electron densities range between $1 < n_0 < 30$ cm^{-3}.
- Magnetic fields within an HII region range from $1 < B_{||} < 10$ μG.
- B has a uniform line-of-sight orientation on scales of 15 - 40 pc.
- There is little or no change in B in the diffuse ISM between 1 -10 cm^{-3}.
- $P_{mag} \approx P_{thermal}$
- The parallel component of the magnetic field in HII regions is consistent with the Galactic magnetic field structure derived by Han & Zhang (2008).
- **Future studies**: RM structure functions to investigate scaling of turbulence.
- Talk: "The role of magnetic fields in controlling the structure of HII regions" (Gary Ferland, Thursday afternoon)