Observations of Magnetic Fields in Nearby HII Regions

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Magnetic Fields in HII Regions

- Many observations of interstellar **B** in molecular clouds, cold HI, large-scale field
- Observe Faraday rotation toward large, evolved HII regions; 'Interstellar Magnetic Lightbulbs'
  - isolate **B** in 3D space
  - trace field where $n_e \approx 1\text{-}10\ cm^{-3}$
- How does **B** compare in different interstellar environments?
- Are **B** fields important in HII region evolution?
- First attempts & results based on 1 or 2 sources
  (Heiles et al 1980, 81)
- Use new all-sky surveys of RM, HII regions

NASA, ESA, N. Smith (University of California, Berkeley) and the Hubble Heritage Team (STScI/AURA)

Faraday Rotation Measure

- Consider linearly polarised wave through a magnetised plasma
- Birefringent phenomenon causes position angle to change, $\Delta\psi = \lambda^2 * \mathrm{RM}$

$$\mathrm{RM} = .81 \int_0^L n_e \mathbf{B}_{||}\, dl \quad \mathrm{rad\ m^{-2}}$$

- To quantify $\mathbf{B}_{||}$, need to know $n_e(l)$
- Observe delay in pulsar arrival times; Dispersion Measure $\mathrm{DM} = \int_0^L n_e\, dl \quad \mathrm{cm^{-3}\ pc}$
- Observe other radiation (recom, f-f); Emission Measure $\mathrm{EM} = \int_0^L {n_e}^2\, dl \quad \mathrm{cm^{-6}\ pc}$
- Combine the three:

$$< \mathbf{B}_{||} >_{los} = \frac{\mathrm{RM}}{.81\ \mathrm{DM}} \qquad < \mathbf{B}_{||} >_{los} = \frac{\mathrm{RM}}{.81\ \mathrm{EM}} < n_e >_{los} \left[1 + \frac{{\sigma_{ne}}^2}{< n_e >^2}\right]$$

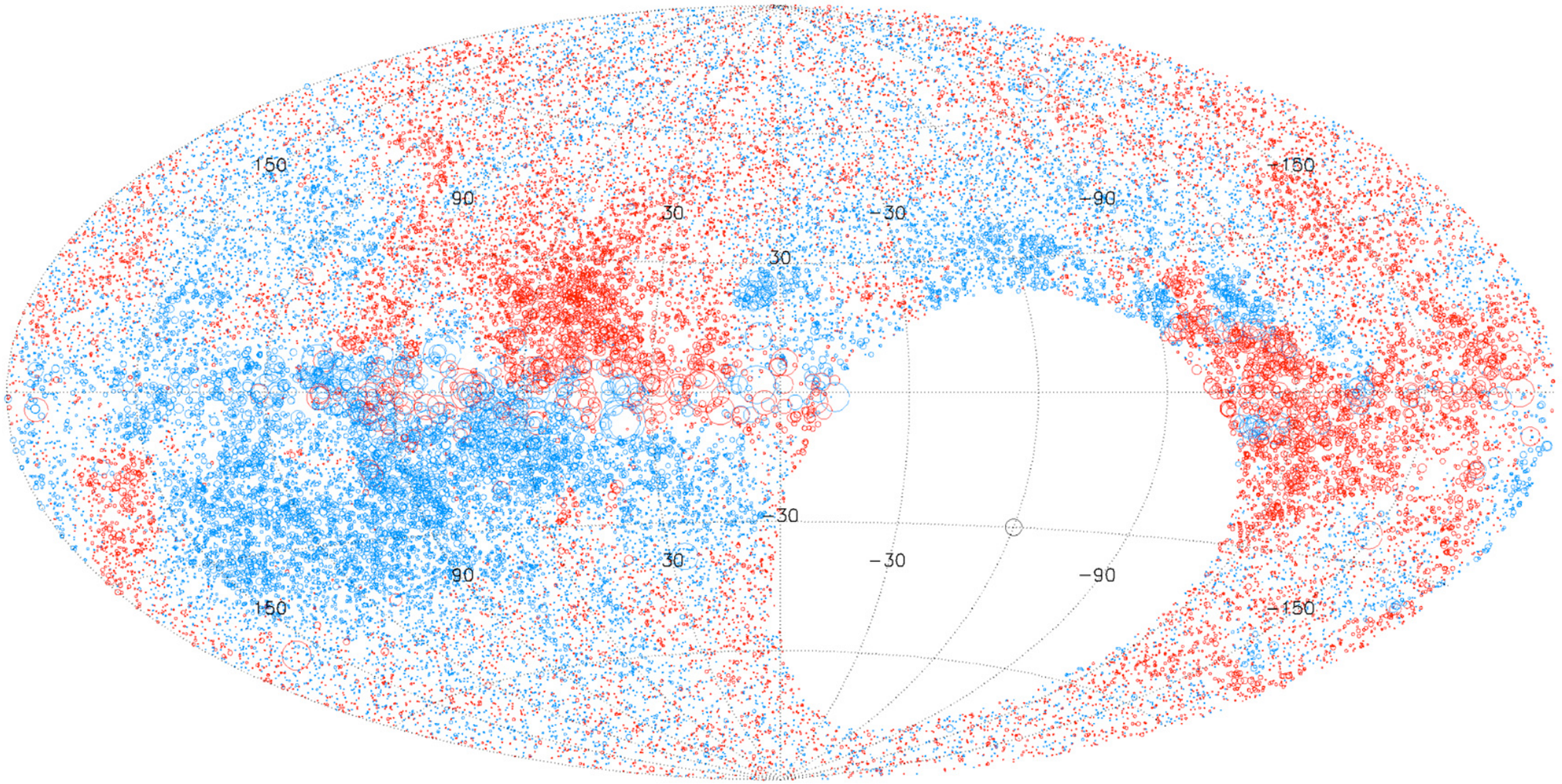
where σ_{ne} is r.m.s. of n_e along the line of sight

Rotation Measure Limitations

- Integrate over identical pathlengths
  - isolate contributions to RM, DM, EM
- Remove RM intrinsic to background source (pulsar, AGN)
- Consider reliability of RMs (λ^2 coverage)
- Requires high areal density of sources
- Derive accurate EM from observations
  - Optical recombination lines (extinction, temperature)
  - Radio recombination lines (non-LTE, faint)
  - Free-free emission (temperature, remove synchrotron contribution)
- Consider variations of n_e, **B** on scales less than angular resolution

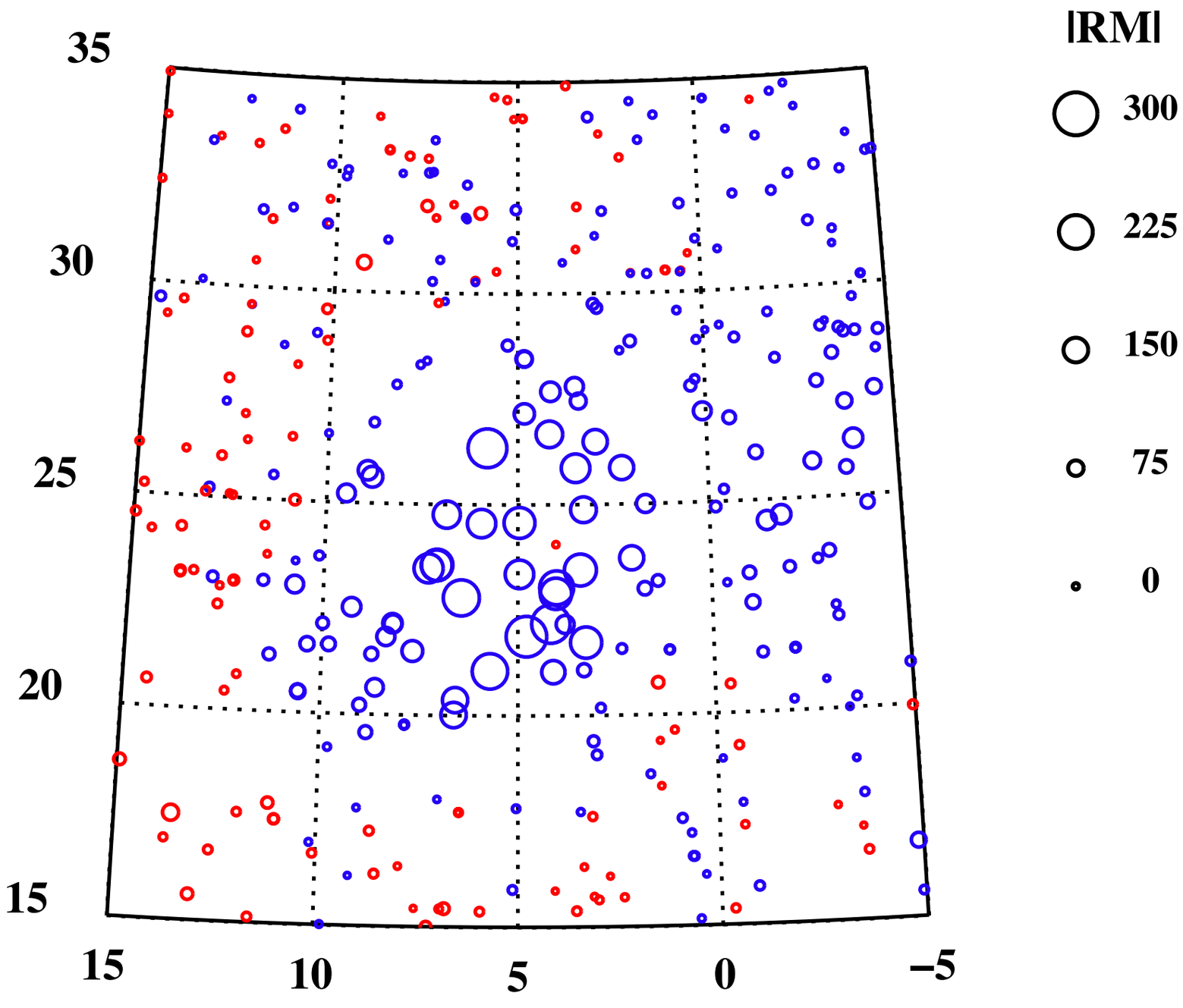
RM Image of the Sky

- Reprocessed NVSS VLA survey, polarisation measured at 2λs near 1.4GHz
- $\delta > -40^{o}$; % polarisation > 0.5%; N=37, 543 RMs (~1 deg^{-2})



Red: Positive RM Blue: Negative RM

Sh 2-27



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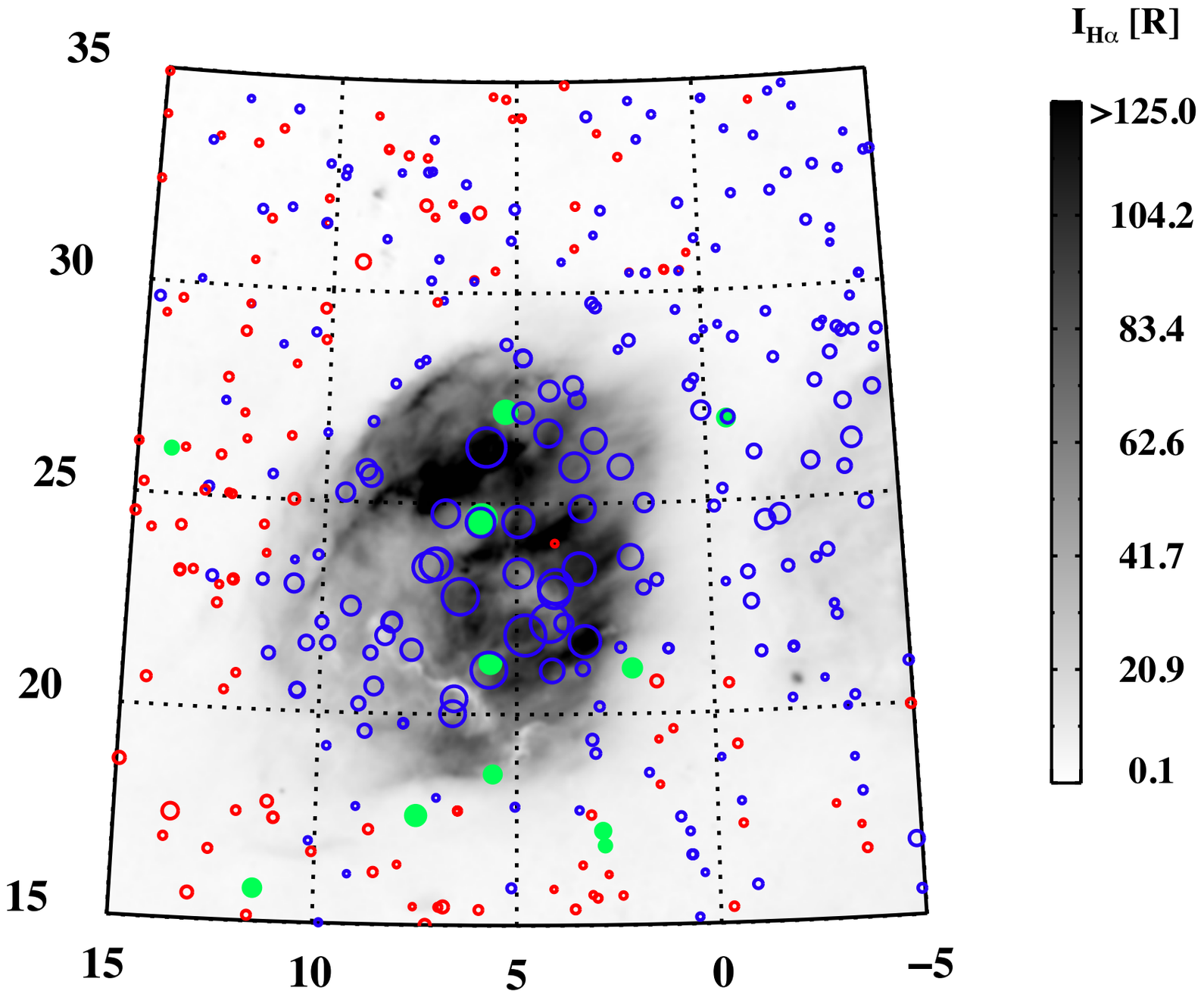
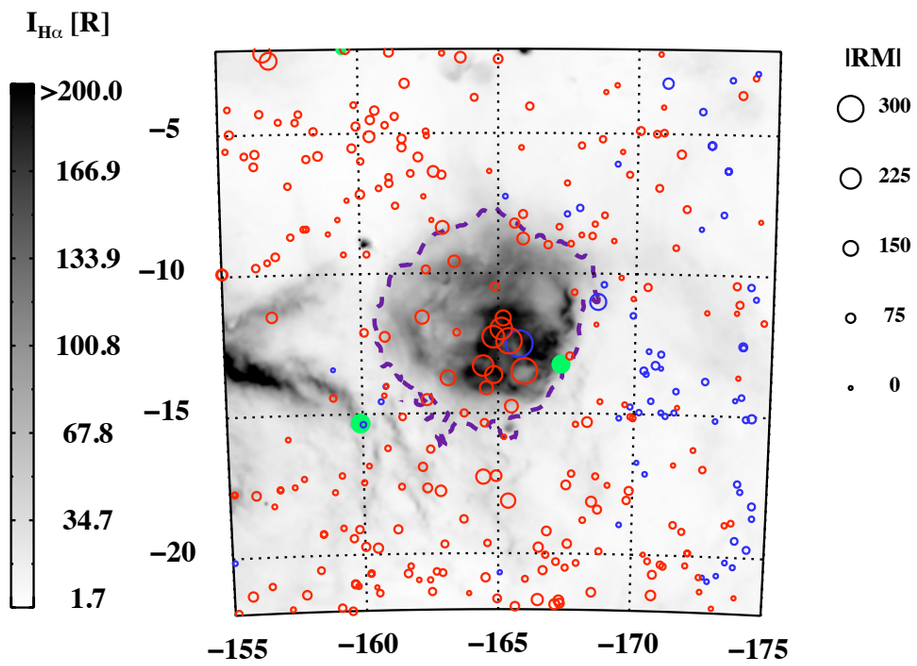
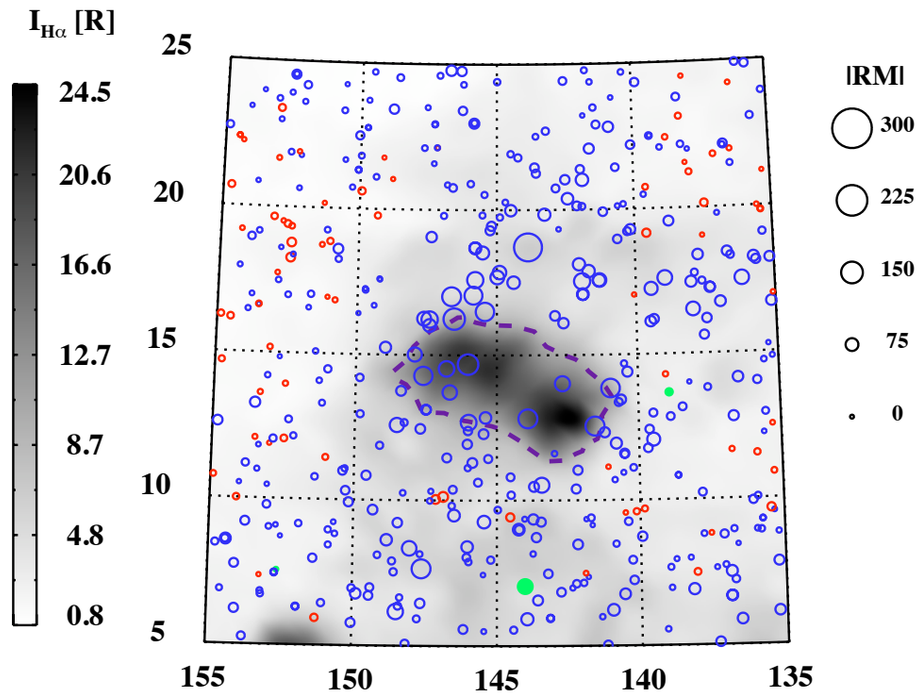
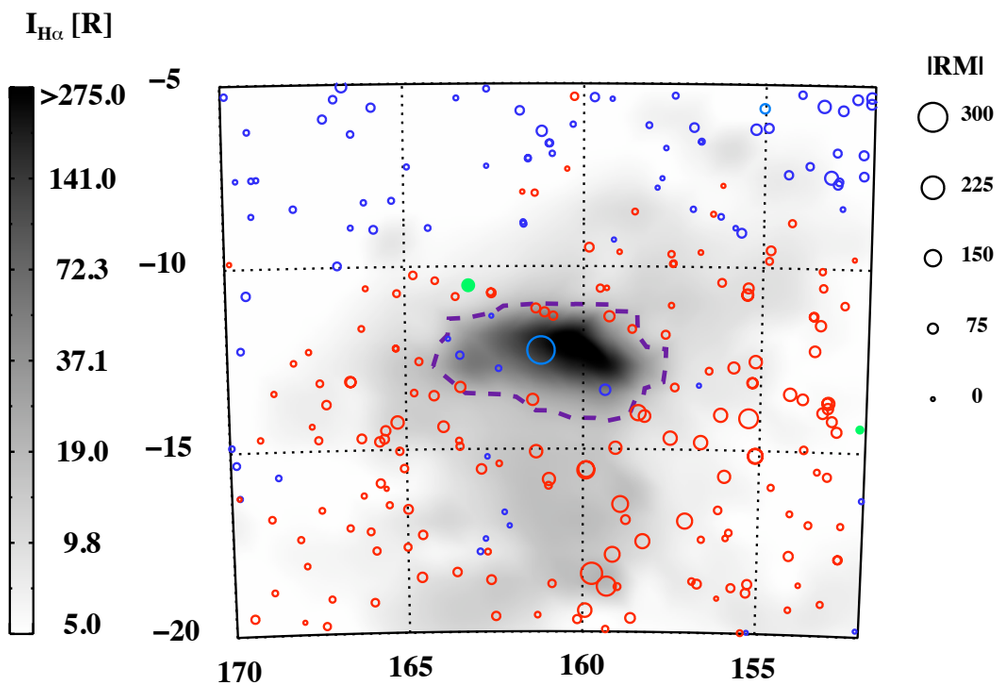
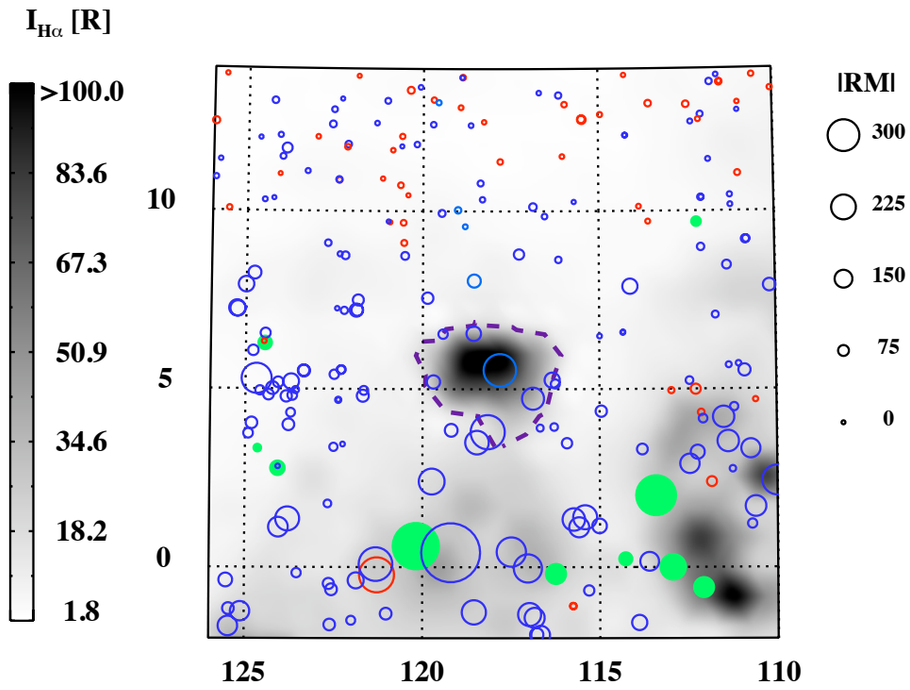


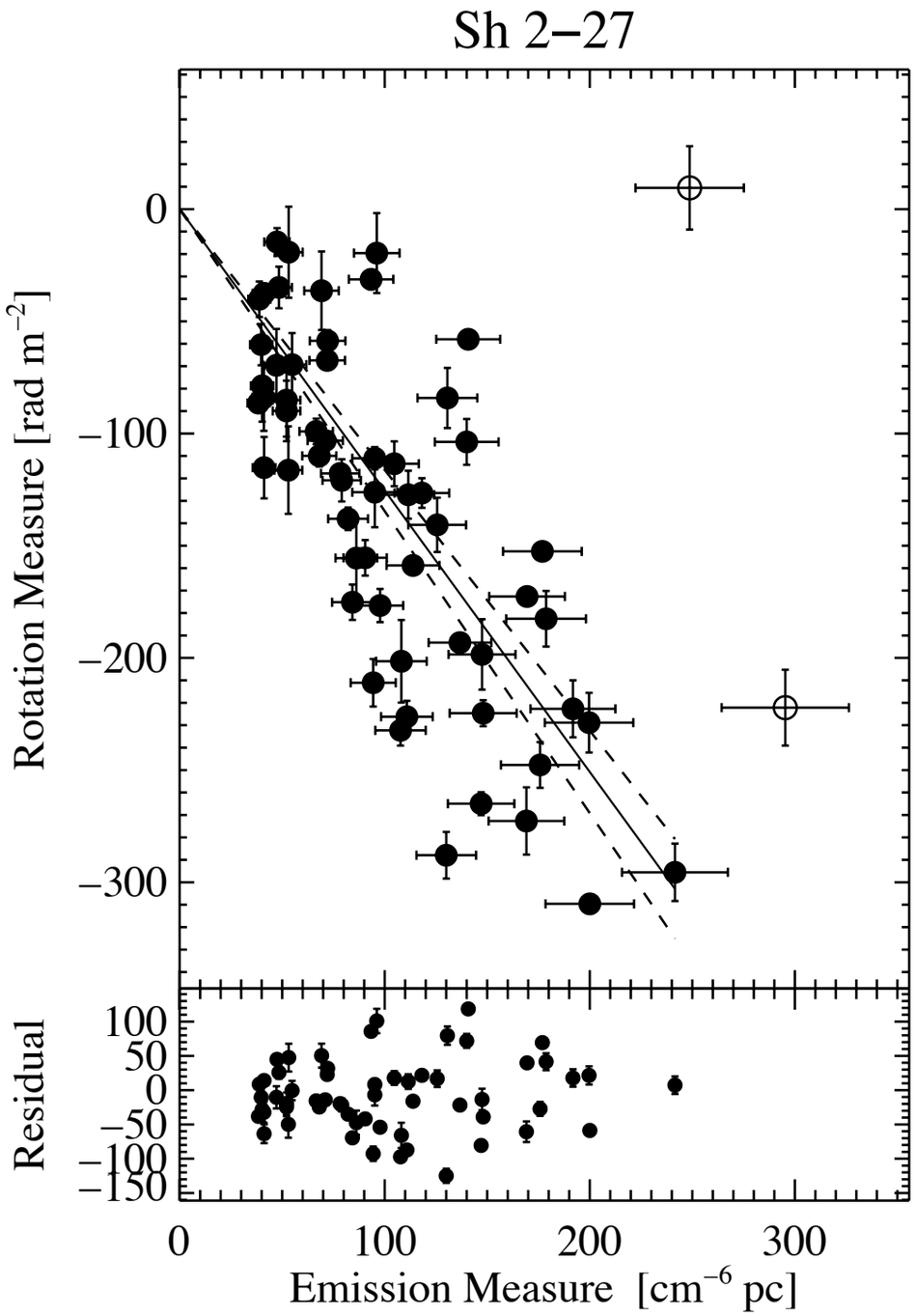

$I_{H\alpha}$ [R]
>200.0
166.9
133.9
100.8
67.8
34.7
1.7
|RM|
300
225
150
75
0
−5
−10
−15
−20
−155
−160
−165
−170
−175


$I_{H\alpha}$ [R]
24.5
20.6
16.6
12.7
8.7
4.8
0.8
|RM|
300
225
150
75
0
25
20
15
10
5
155
150
145
140
135


$I_{H\alpha}$ [R]
>275.0
141.0
72.3
37.1
19.0
9.8
5.0
|RM|
300
225
150
75
0
−5
−10
−15
−20
170
165
160
155


$I_{H\alpha}$ [R]
>100.0
83.6
67.3
50.9
34.6
18.2
1.8
|RM|
300
225
150
75
0
10
5
0
125
120
115
110

Combining RM and EM



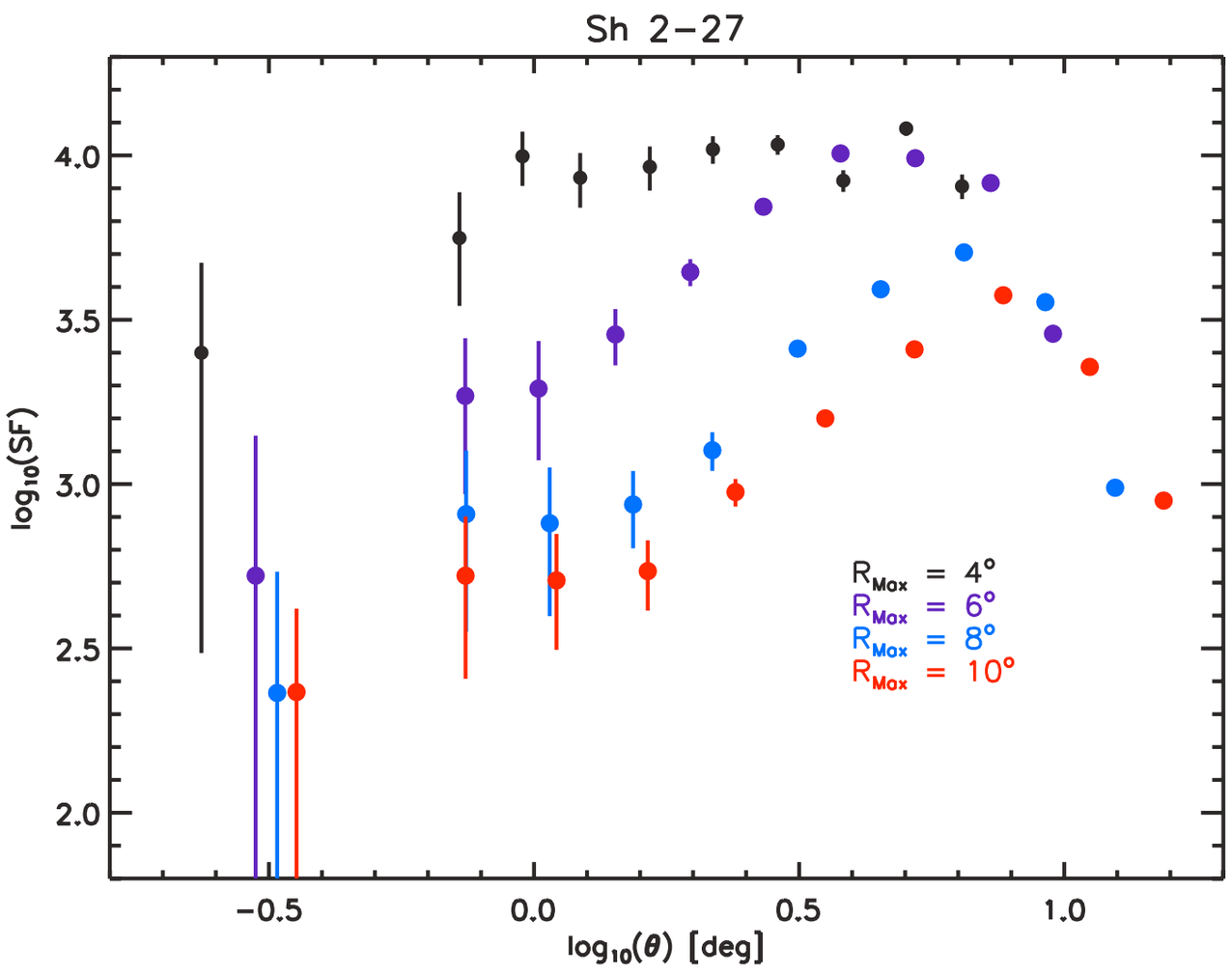
- Identify boundary of HII region
- Remove background+foreground contribution
- Correlation shows HII region is magnetised
- Each point is l.o.s. measure of $\mathbf{B}_{||}/n_e$
- Dust correction to EM
  - IR dust maps (E_{B-V}) or free-free (WMAP)
- Estimating $\langle n_e \rangle$
  - Strömgren: $n_e \approx R_S^{-3/2}\, Q_0^{1/2}\, T_e^{3/8}$
  - $n_e \approx \sqrt{(EM/fL)}$ f = l.o.s. filling factor
- Compare magnetic and thermal energy
  - $U_{mag} > B_{||}^2/8\pi$ $U_{therm} = 3n_e kT$

Results

Name	*	R [pc]	N_{RM}	RM/EM	$C_{H\alpha}$	$\langle n_e \rangle$ [cm^{-3}] f=0.2	$\langle B_{\parallel} \rangle$ [μG]	U_{mag}/U_{ther}
Sh 2-27	O9.5V	15	58	-1.2 ± 0.2	1.7	6.8	-13	0.27
Sh 2-264	O8III	35	10	+0.4 ± 0.2	1.7	6.3	+4	0.03
Sh 2-220	O7.5 III	20	8	-1.3 ± 0.3	1.4	5.7	-11	0.36
Sivan 3	O9.5Ia	40	11	-3.4 ± 1.1	1.4	1.1	-6	0.54
Sh 2-171	O7V	30	7	-1.1 ± 0.3	3.5	4.2	-11	0.06

RM Structure Function

- Consider pairs of RMs separated by $\theta \pm \delta\theta$
- Calculate an average $SF(\theta) \equiv < (RM_i - RM_j)^2 >$



- "Poor man's power spectrum"
- Characterises angular scale of variations

- Slope of SFs used to constrain inner/outer scale of variation (turbulence)

(Haverkorn et al 2006, Feain et al 2009)

- Consider points within R_{Max} of HII region centre

- SF steepens, falls off at large θ

Summary

- Uniform **B** fields thread nearby HII regions; scales of tens of parsecs
    - No enhancement at edges
- Line-of-sight field strengths ≈ 10 μG
    - Limitations to technique allows fields to vary by factor of a few
    - Similar to diffuse HI, Galactic neighborhood
    - Pulsar RMs provide consistent results
- Magnetic energy density 5% - 50% of thermal energy density
    - **B** field not playing dominant role in evolved, ‘classical’ HII regions
- Slope of structure function increases with cutoff radius
    - Geometry ? Scale of turbulence?

- What is B_{random} ? B_{total} ?
- Compare to evolutionary models of HII regions; runaway O stars
- How does field compare to large-scale Galactic field models?

The Future

- Australian SKA Pathfinder
  36 12m dishes @
  Murchison in WA,
  0.7 - 1.8 GHz,
  30 deg^2 FOV
- ASKAP Survey Science Project: POSSUM
- Aim: 3x10^6 RMs across southern sky
- 100 RMs deg^{-1}
- Use RM synthesis technique to extract multiple RMs in one line of sight