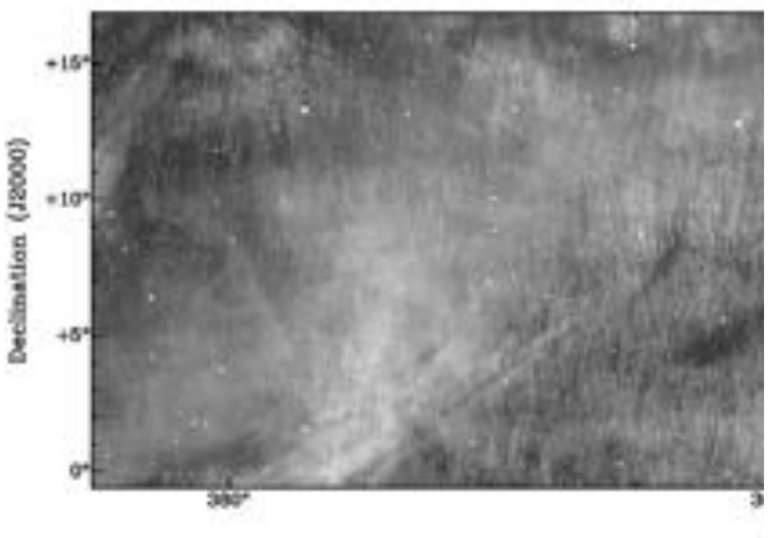
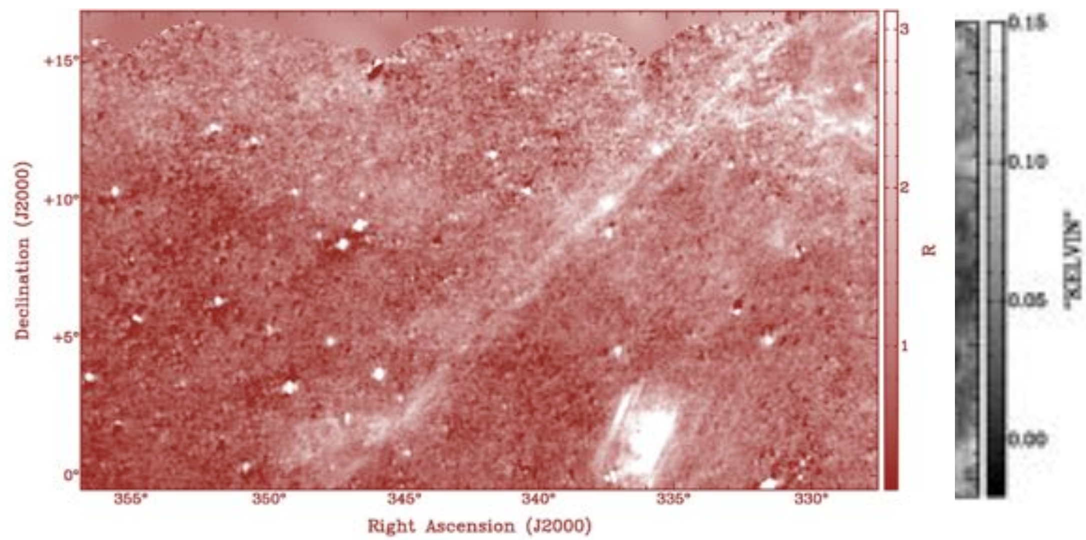
Magnetic fields in and around a nearby ionized intermediate-velocity filament





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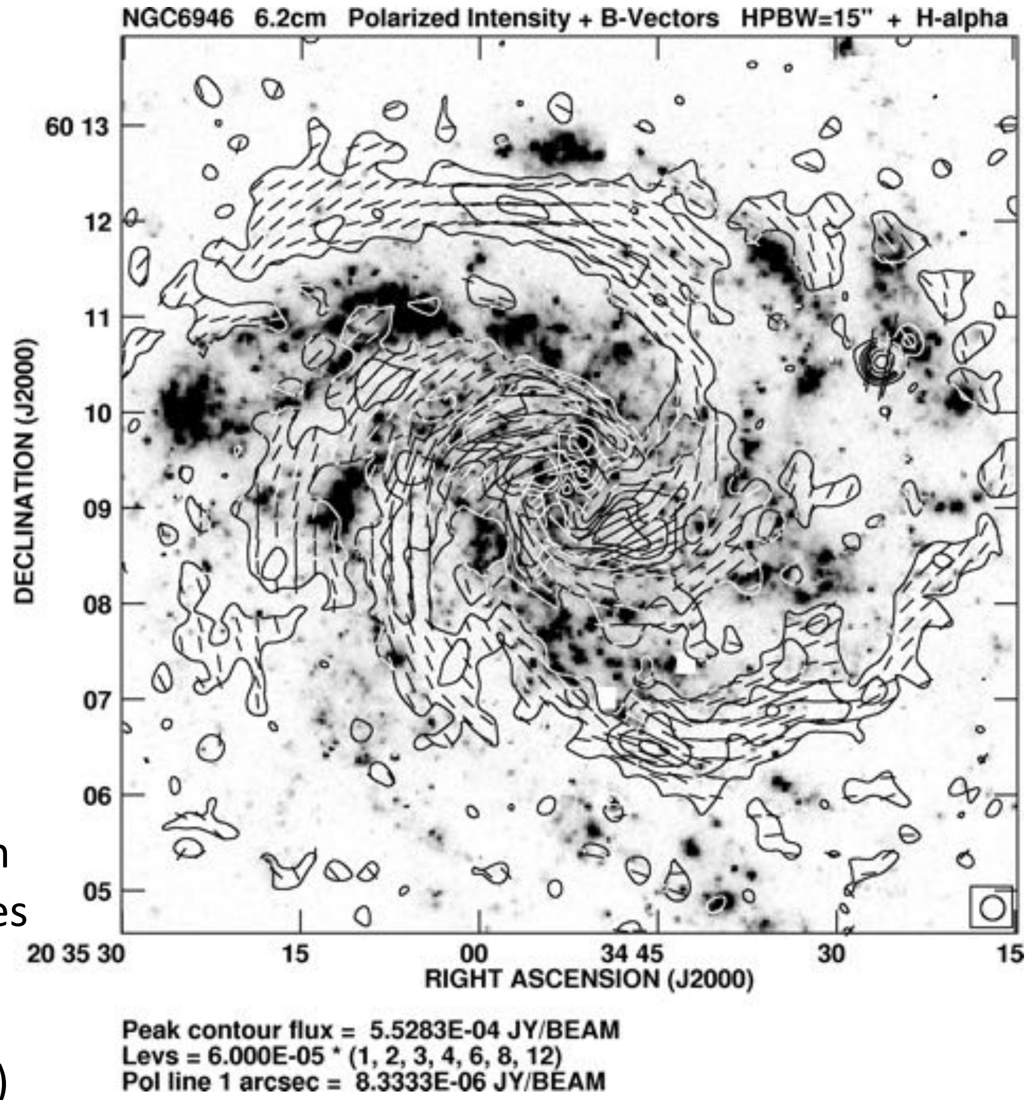
Magnetic Fields in Star Forming Galaxies

- ❑ Large scale magnetic field (10 kpc)
- ❑ Small scale structure associated with ISM turbulence
- ❑ Coupling between large and small scales (stellar feedback, dynamo, star formation, …)
- ❑ Halo magnetic field

Observations:

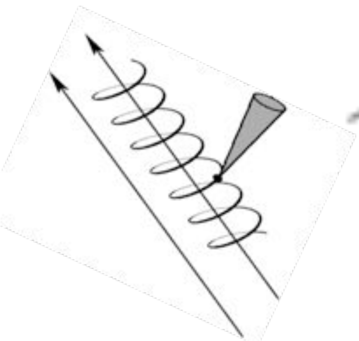
- ➢ Diffuse polarized synchrotron emission
- ➢ Faraday rotation of background sources and diffuse emission
- ➢ Zeeman splitting
- ➢ Dust polarization (extinction/emission)

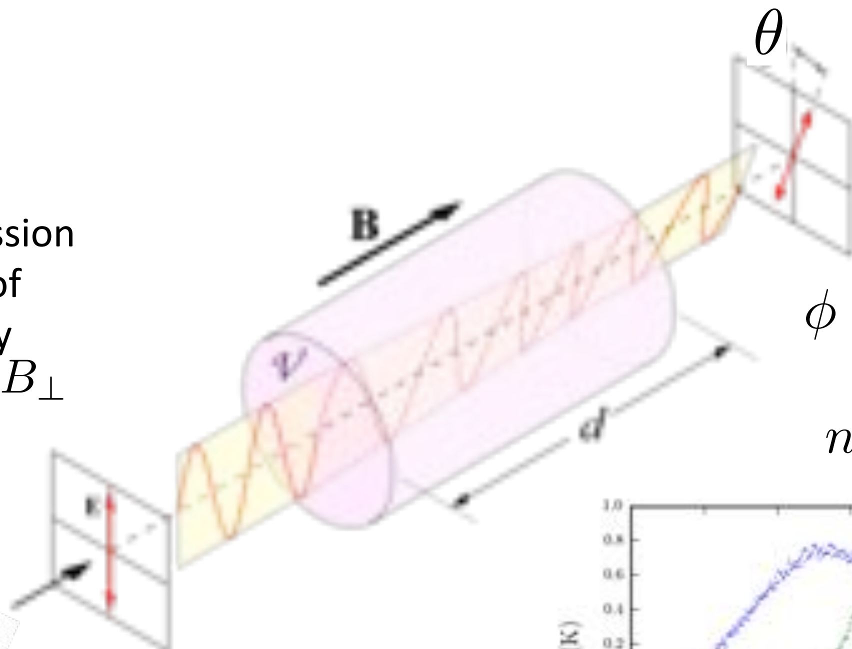


NGC 6946 Beck (2007)

Faraday Rotation

Synchrotron emission at source, plane of polarization in sky perpendicular to $B_\perp$

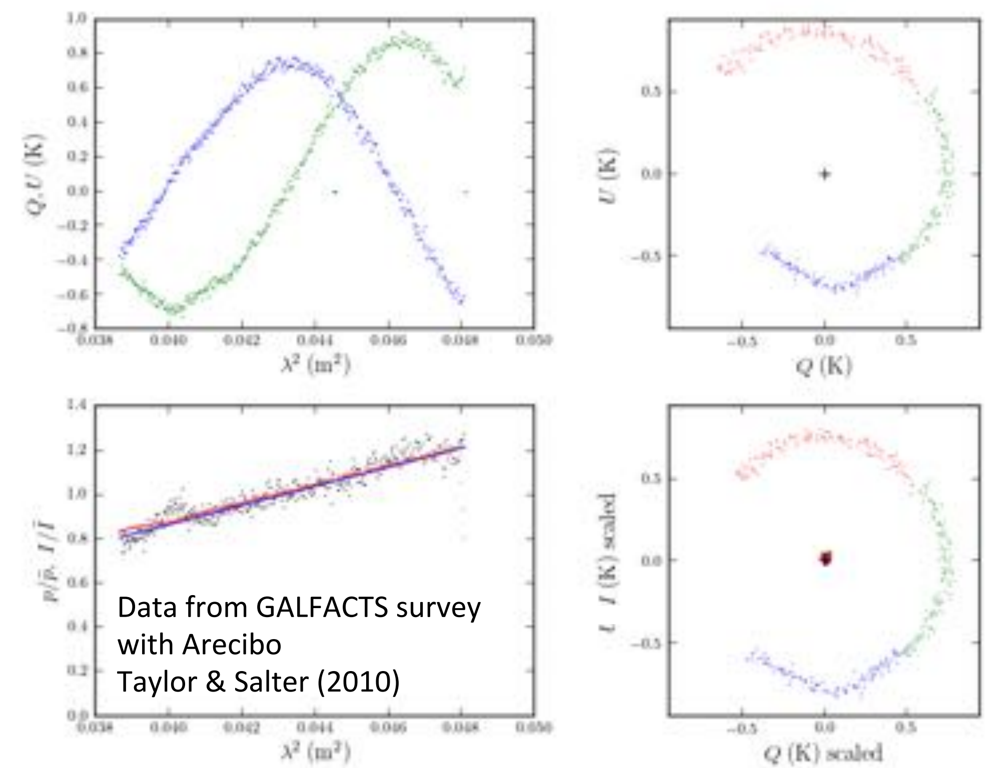




$$\theta = \theta_0 + \phi\lambda^2$$

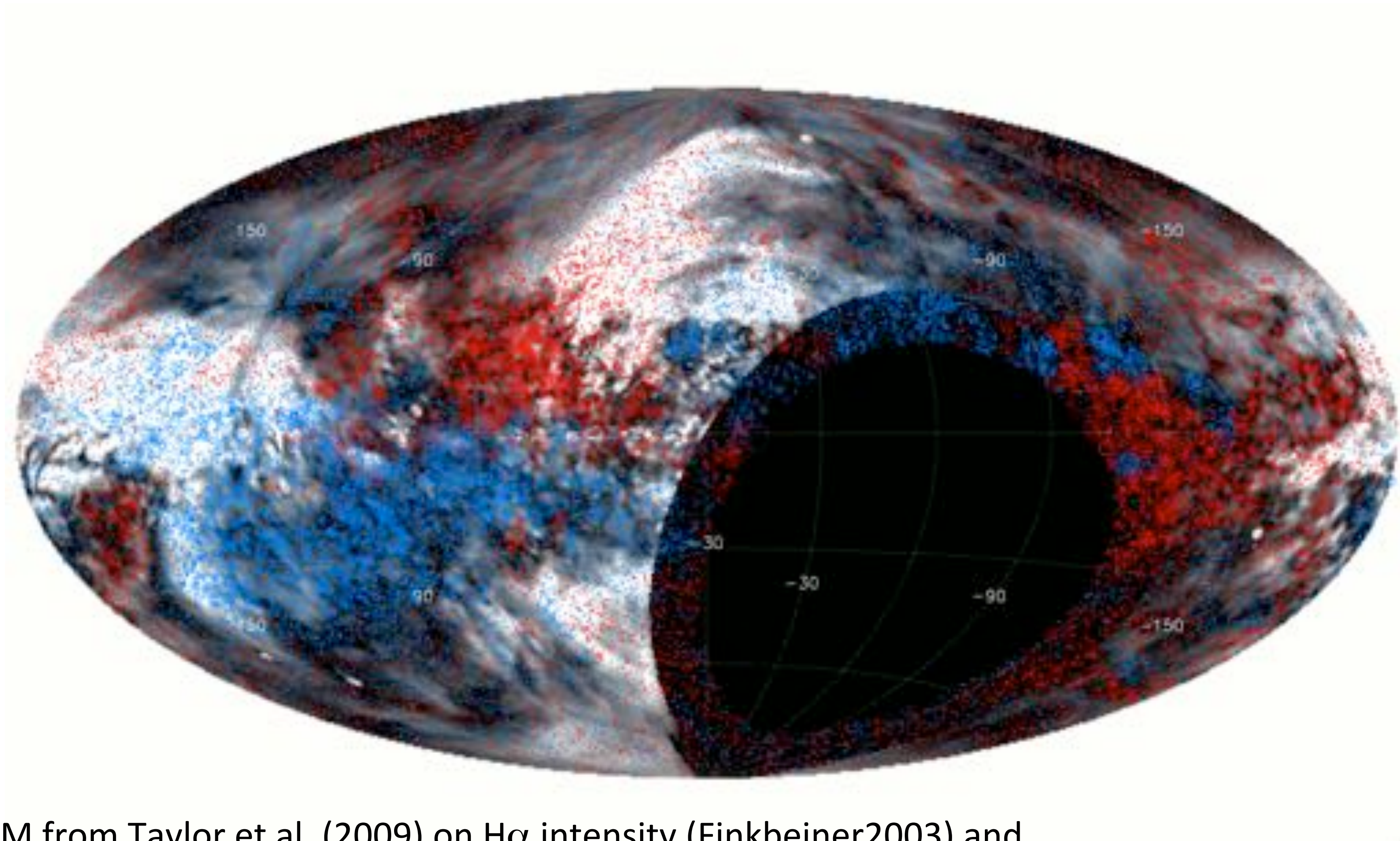
$$\phi = 0.812 \int n_e \vec{B} \cdot d\vec{l} \ \text{rad m}^{-2}$$

$$n_e \text{ in cm}^{-3}, B \text{ in } \mu\text{G}, l \text{ in pc}$$



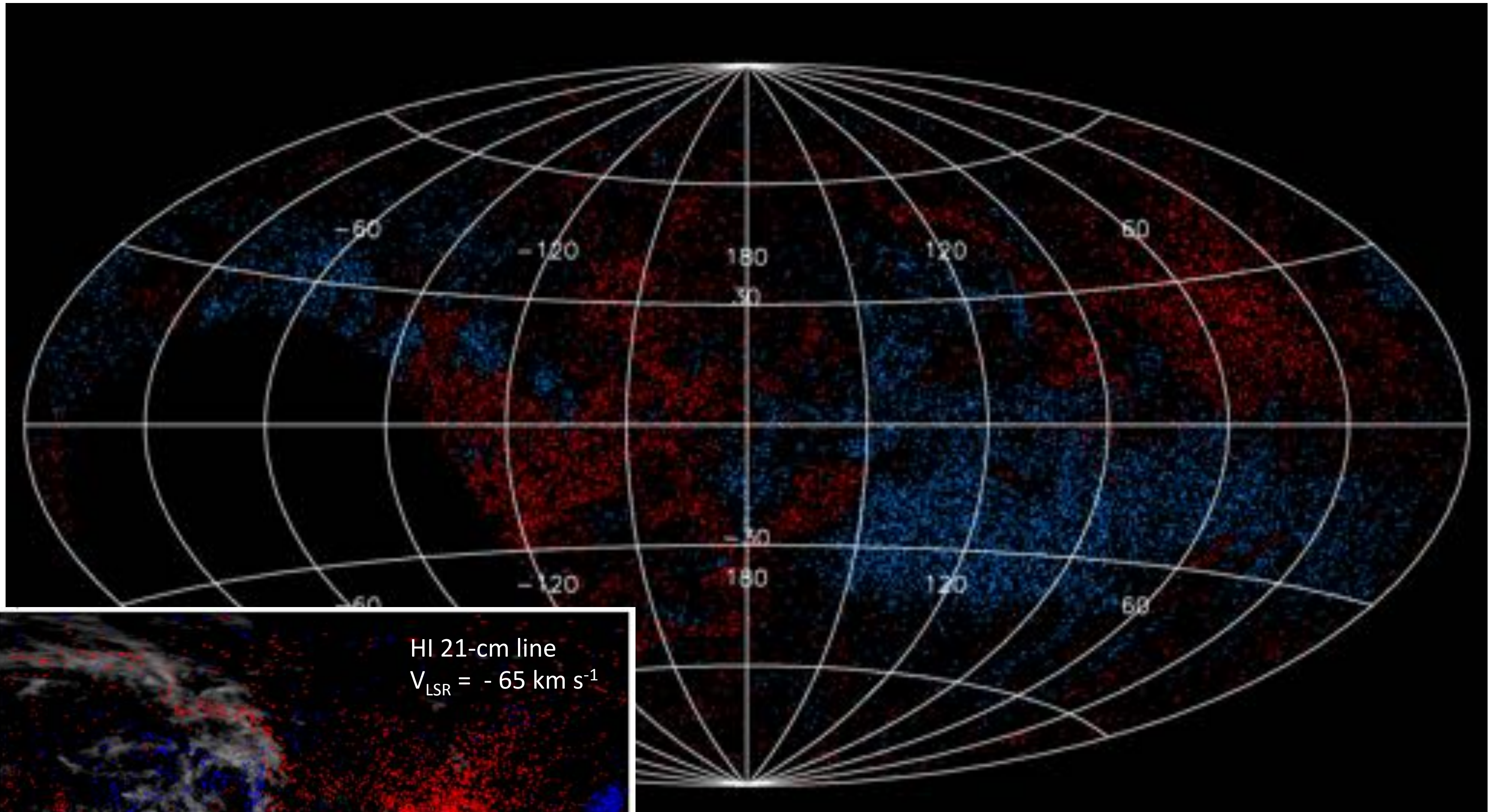
Data from GALFACTS survey with Arecibo
Taylor & Salter (2010)

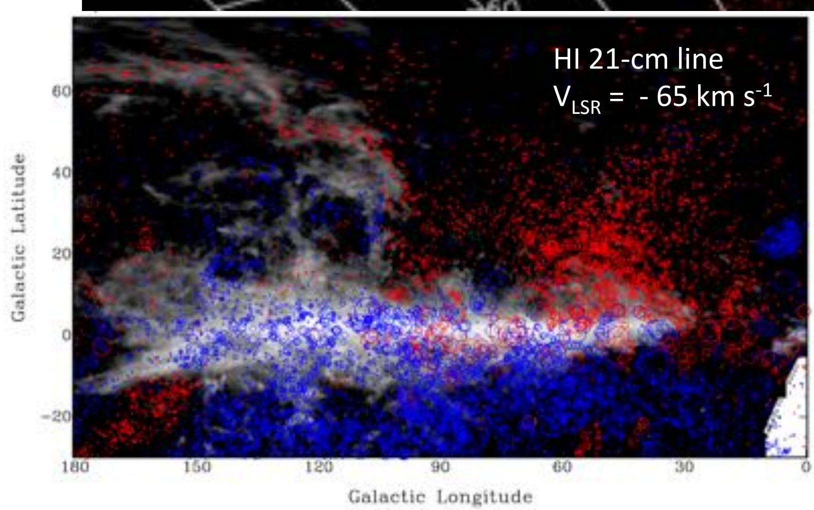
Faraday Rotation in the (local) ISM



RM from Taylor et al. (2009) on Hα intensity (Finkbeiner2003) and diffuse polarization (Wolleben et al. 2006)

|RM| > 25 rad m^{-2} centered on l = 180^o



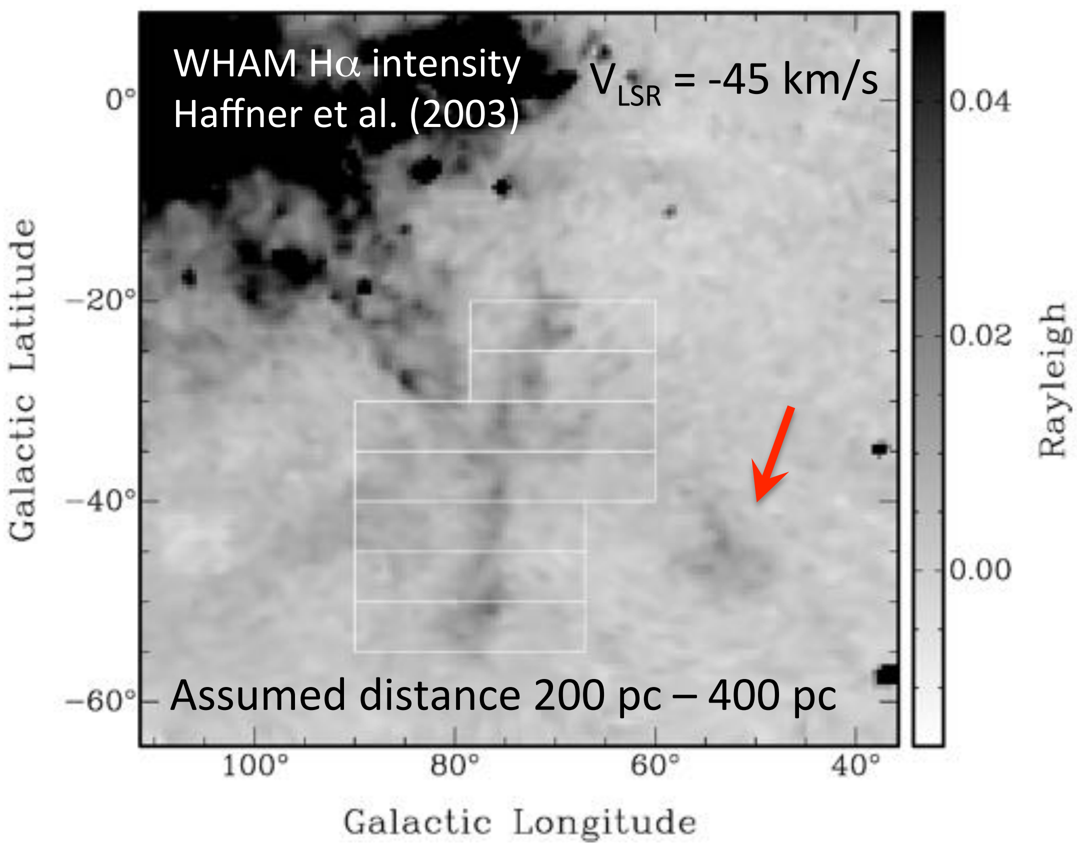


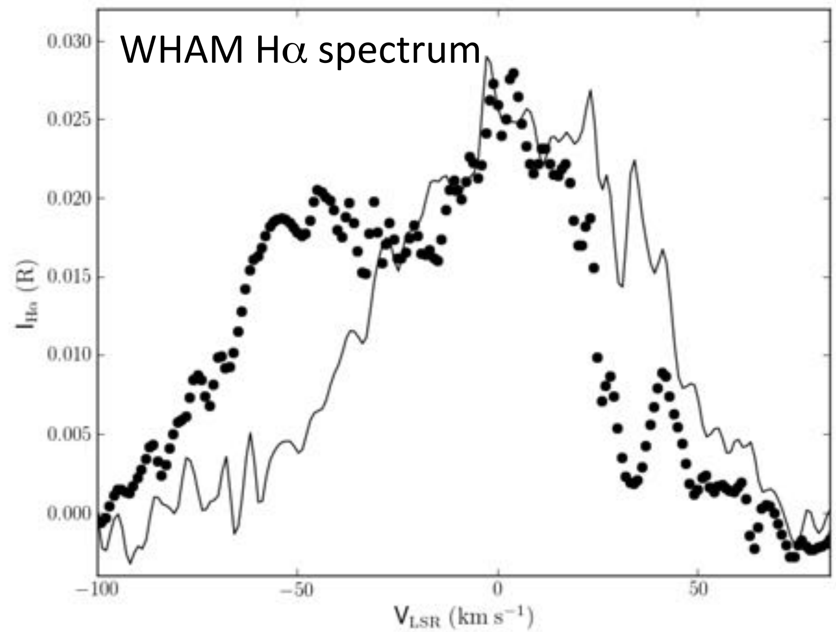
$$\phi = 0.812 \int n_e B_{\parallel} dl \quad \text{rad m}^{-2}$$

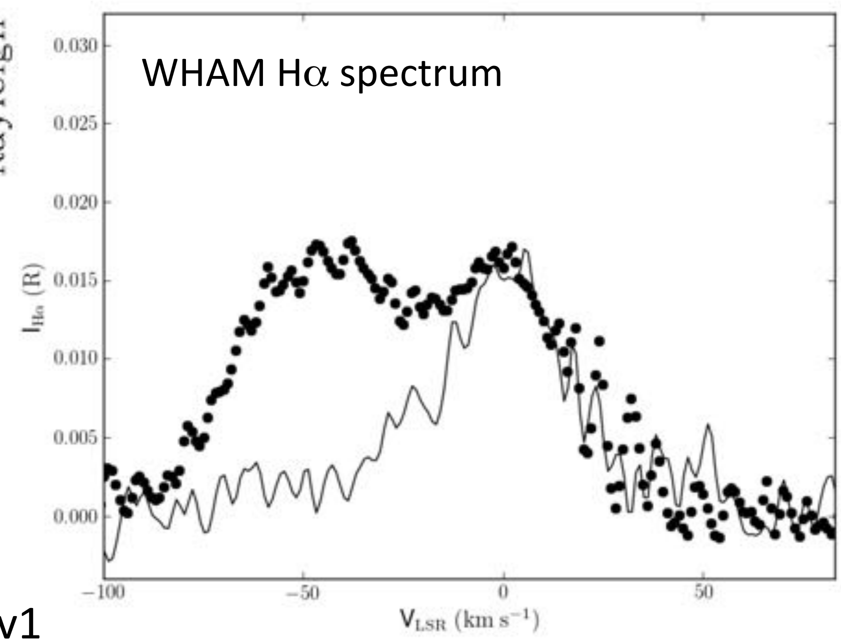
How to interpret the data without model of electron density n_e ?

Magnetic Field In An Intermediate-Velocity Ionized Filament With Nearby Cloud

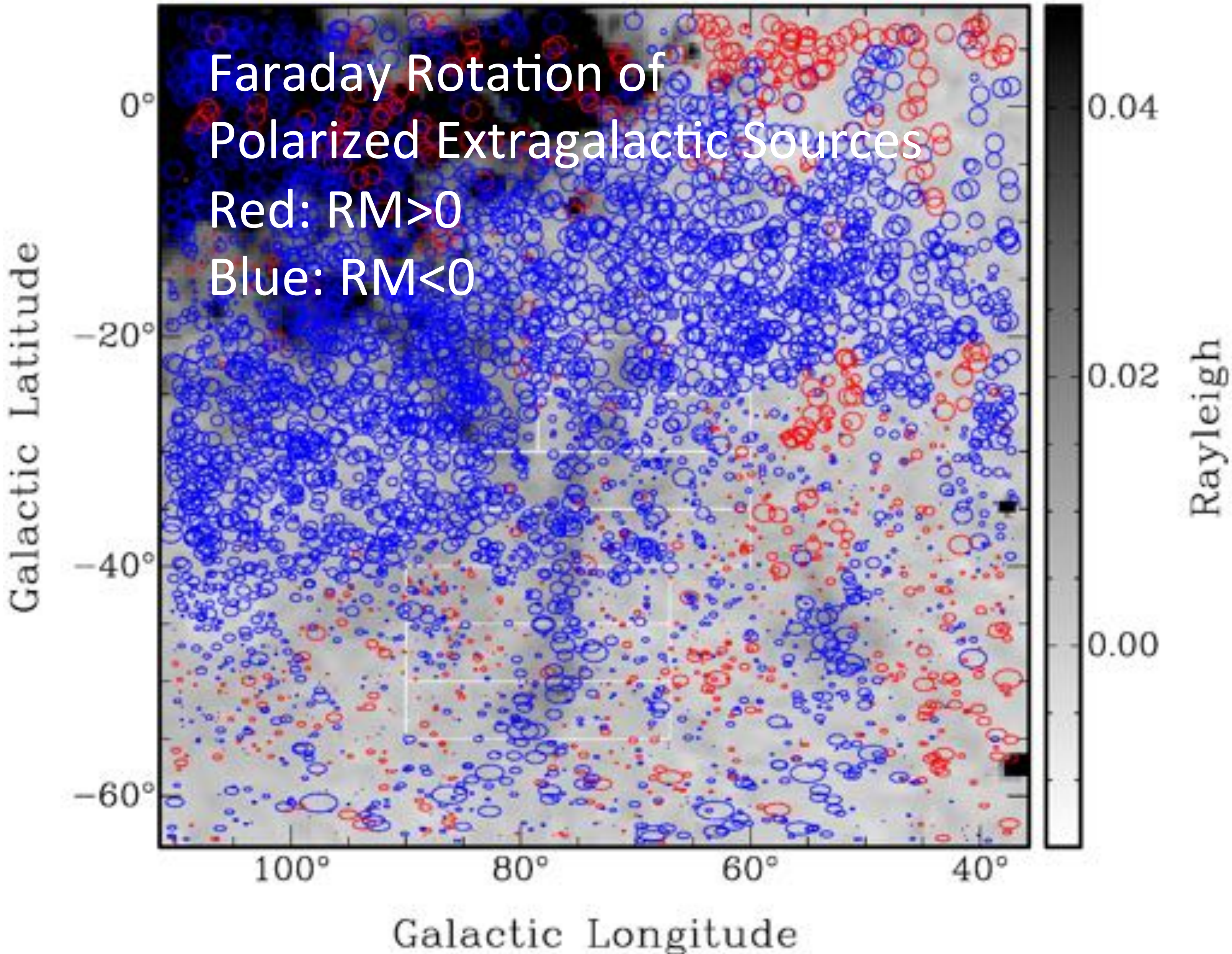
Stil & Hryhoriw (2016)







See also Planck foreground paper arXiv 1506.0660v1



RM data from Taylor, Stil & Sunstrum (2009)

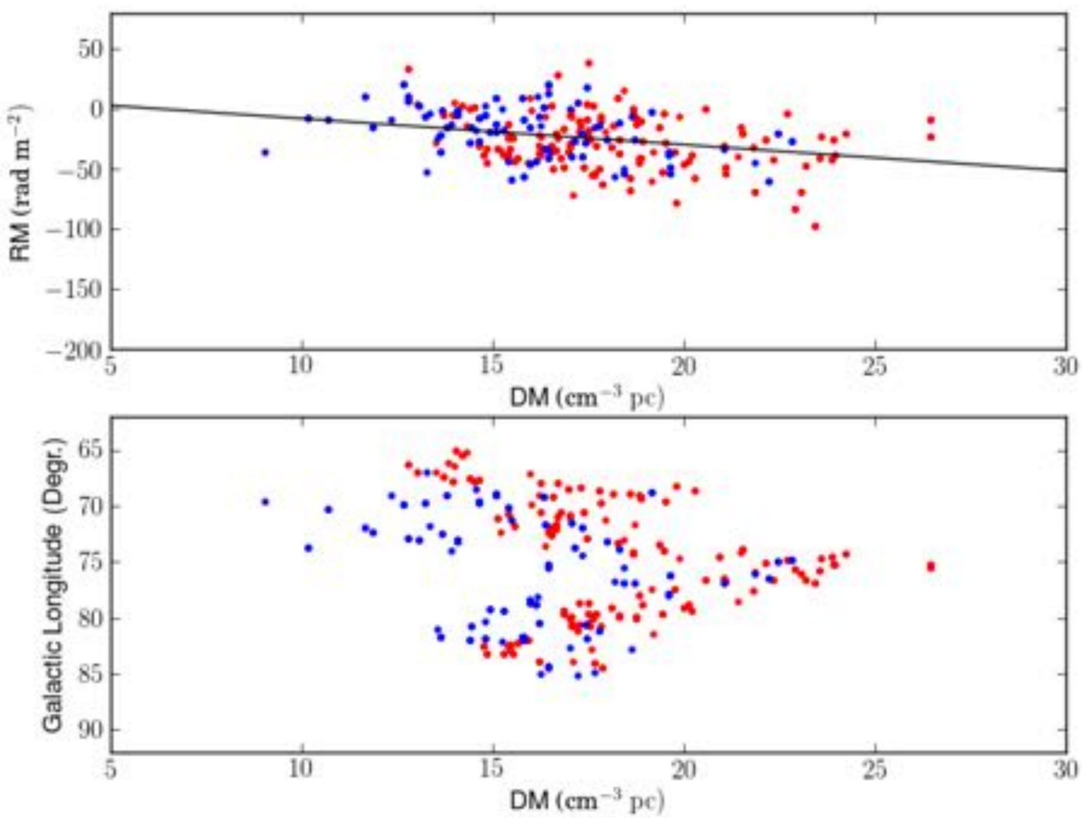
Magnetic Field Strength

Indirect estimate of dispersion measure from emission measure using relation derived by Berkhuijsen et al. (2006) for pulsars.

$$EM = \int n_e^2 dl \longrightarrow DM = \int n_e dl \qquad \langle B_\parallel \rangle = \frac{\int n_e B_\parallel dl}{\int n_e dl}$$

$$\langle B_\parallel \rangle = -2.8 \pm 0.8 \ \mu\mathrm{G}$$

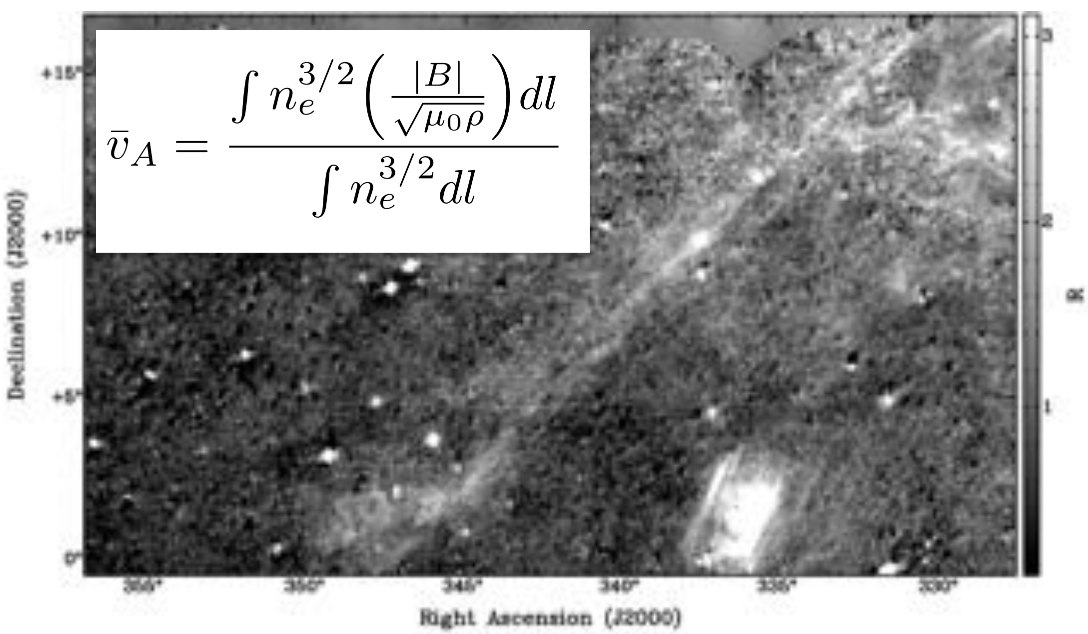
Density-weighted mean l.o.s. component



A low-plasma-β filament

Lower limit to the density-weighted Alfven velocity using **Faraday depth** ϕ and **emission measure** EM (Stil & Hryhoriw 2016):

$$\bar{v}_A \geq (0.820 \text{ km s}^{-1}) \mu_e^{-1/2} f^{-1/4} \left(\frac{L}{100 \text{ pc}} \right)^{-1/4} \mathcal{R}^{-1} \left[\frac{|\phi|}{EM^{3/4}} \right]$$



$$\bar{v}_A = \frac{\int n_e^{3/2} \left(\frac{|B|}{\sqrt{\mu_0 \rho}} \right) dl}{\int n_e^{3/2} dl}$$

VTSS Hα intensity (Dennison et al. 1998)

Filament: $\bar{v}_A \geq 9 - 33 \text{ km s}^{-1}$

Nearby cloud: $\bar{v}_A \geq 45 \text{ km s}^{-1}$

Sound speed: $c_S \approx 10 \text{ km s}^{-1}$

$$\beta = \frac{p_{gas}}{p_{\text{mag}}} = \frac{c_S^2}{v_A^2} \quad < 0.1 - 1$$

$\beta \to \infty$ hydrodynamical limit

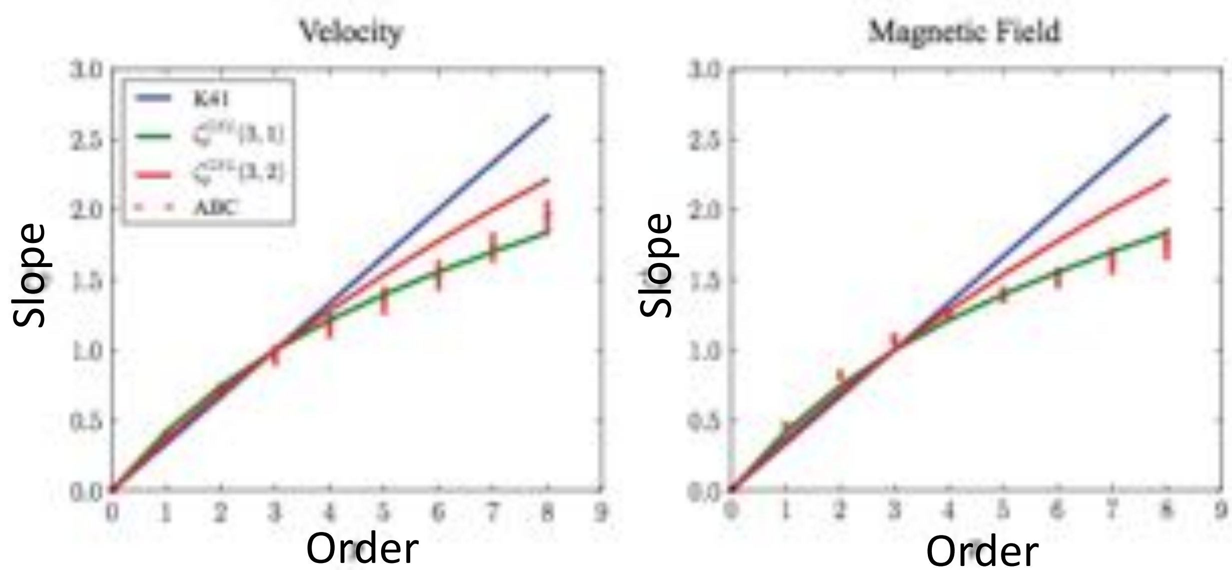
$\beta = 1$ equipartition

Turbulent Properties Measured With Structure Functions

$$D_n(\theta) = \frac{1}{M}\sum_{i=1}^{M} |\phi(x_i + \theta) - \phi(x_i)|^n$$

Fit Power law to $D_n(\theta)$ for different orders n, and plot slope versus order.

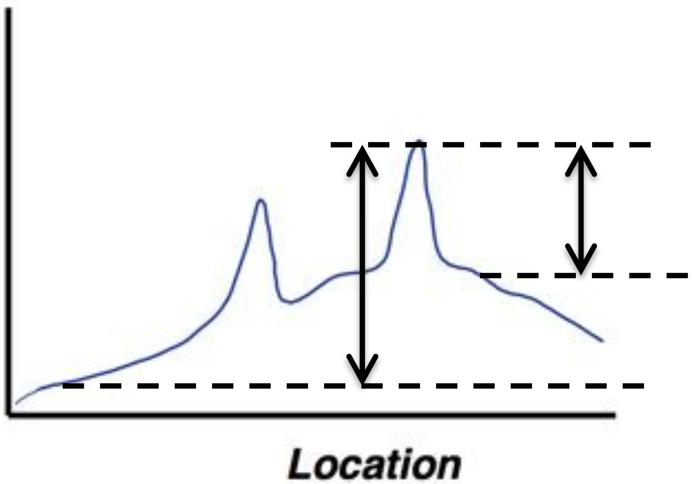
Intermittency of ISM turbulence from MHD simulations by Falgarone et al. (2015):



Kolmogorov (1941)
Self-similar model
gives straight line.

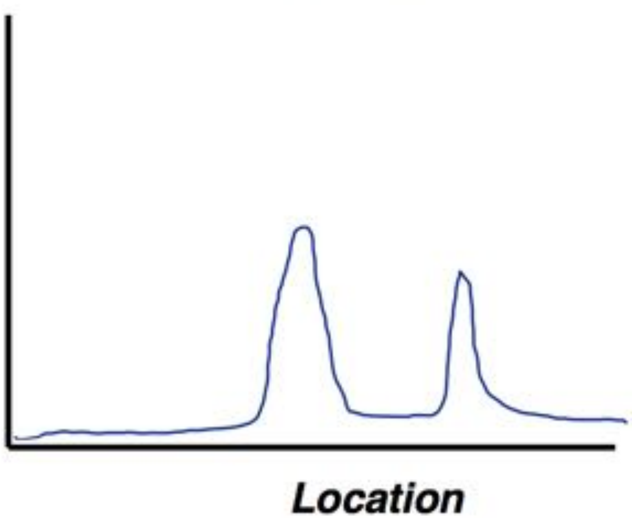
Red/green:
She-Leveque (1994)

Turbulent Properties Measured With
e Functions

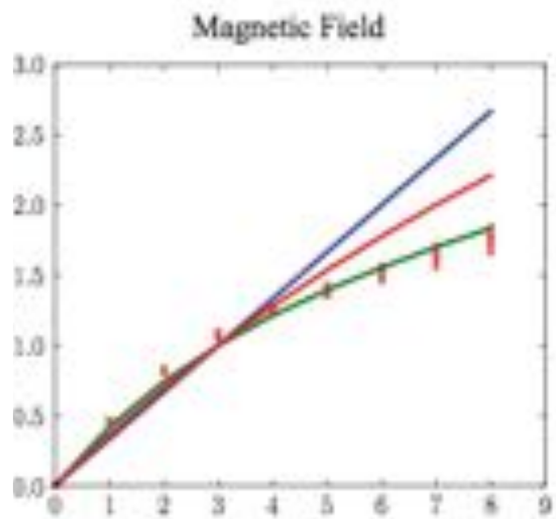


$$|\phi(x_i + \theta) - \phi(x_i)|^n$$

ders n, and plot slope versus order.



MHD simulations by Falgarone et al. (2015):



Order

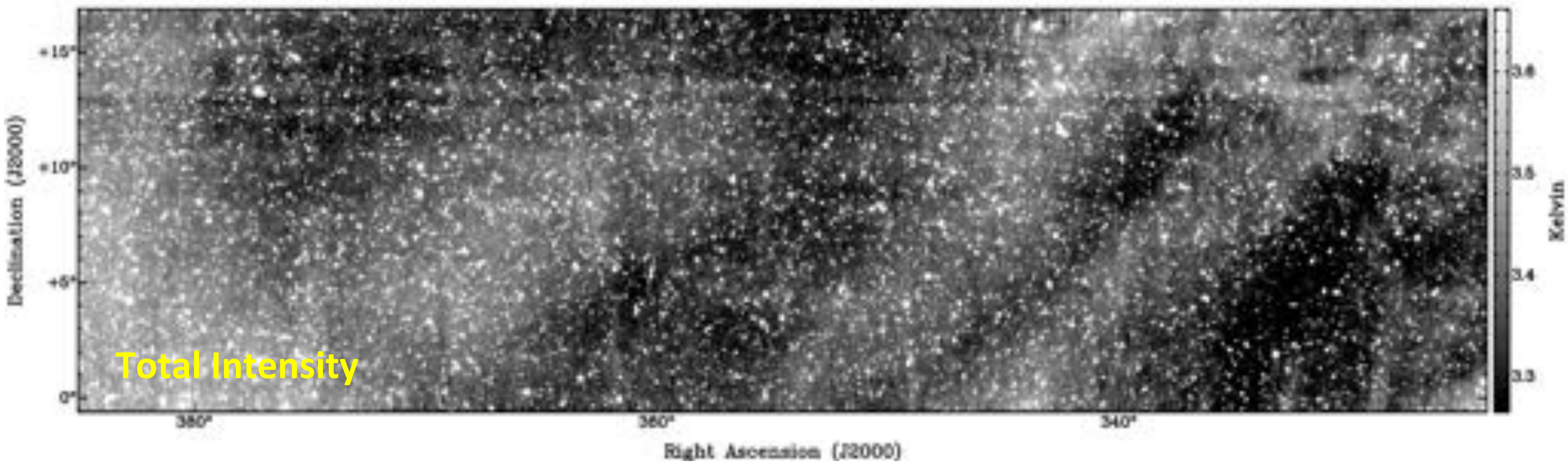
Order

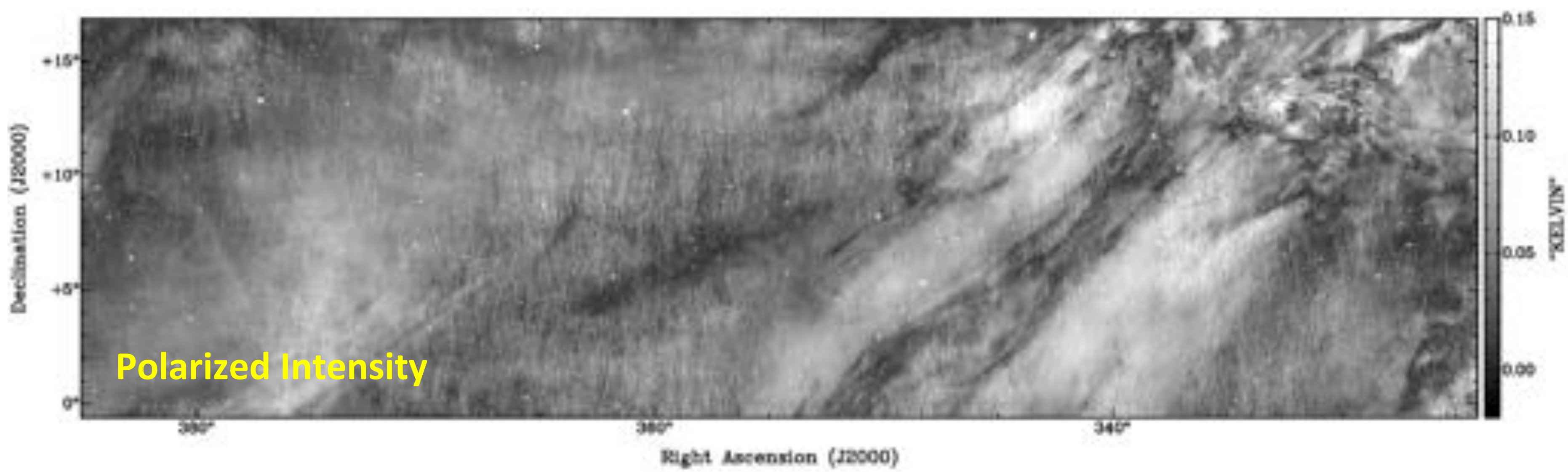
Kolmogorov (1941)
Self-similar model
gives straight line.

Red/green:
She-Leveque (1994)

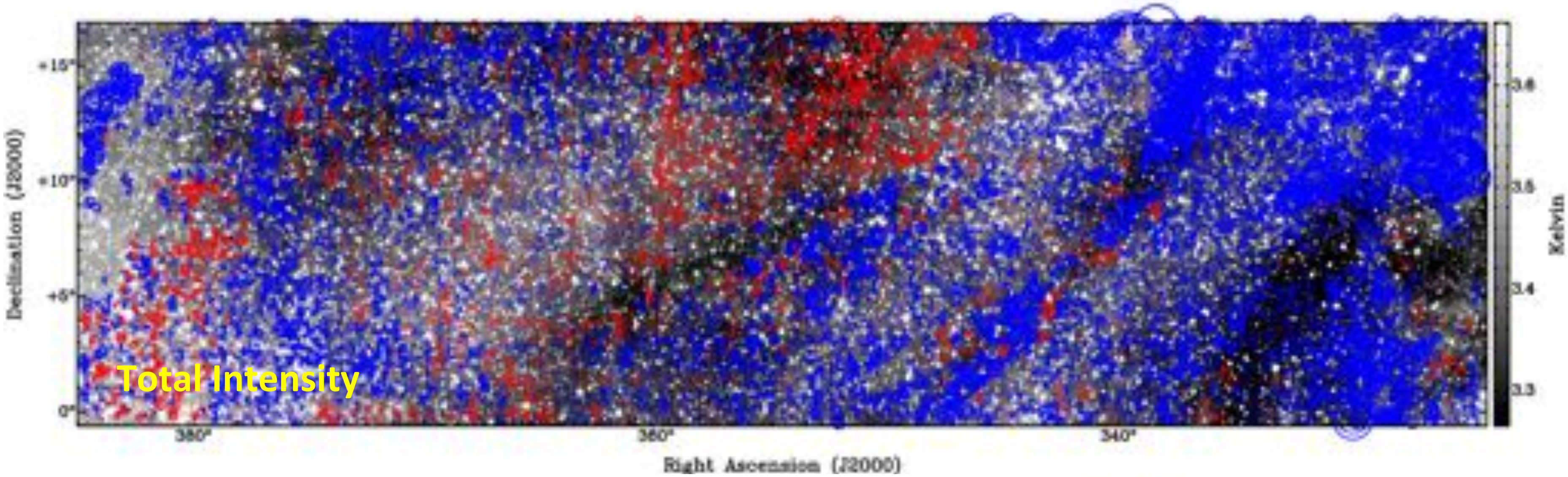
Synchrotron halo around the filament
GALFACTS data

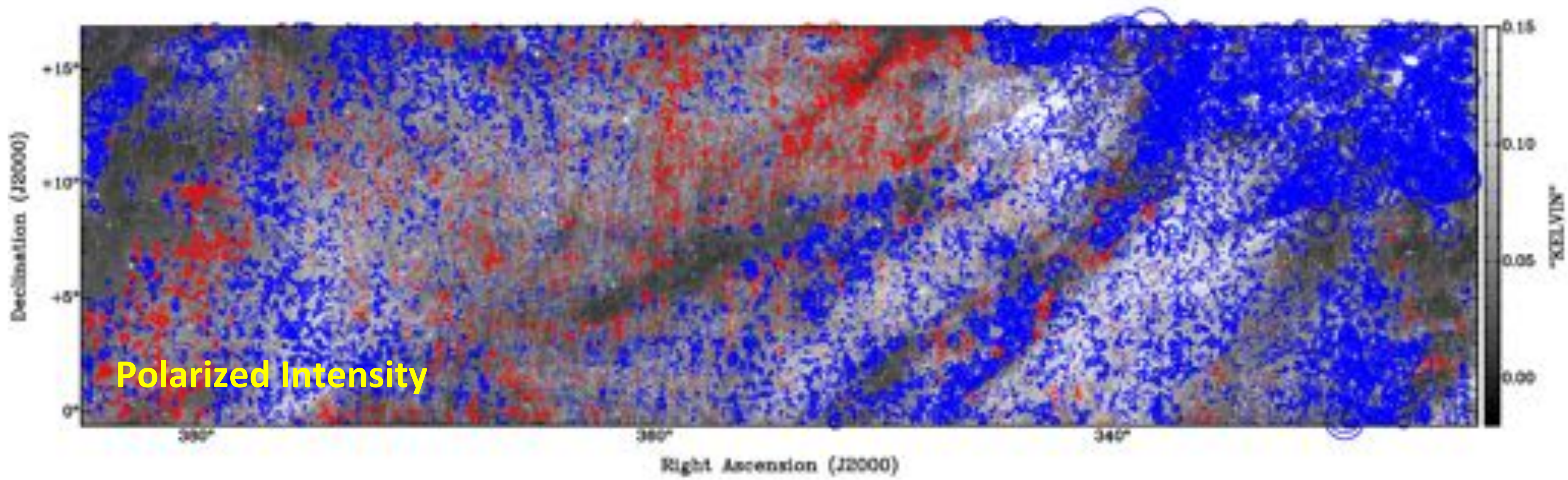
First reported in Planck foreground paper arXiv 1506.0660v1, highly polarized.



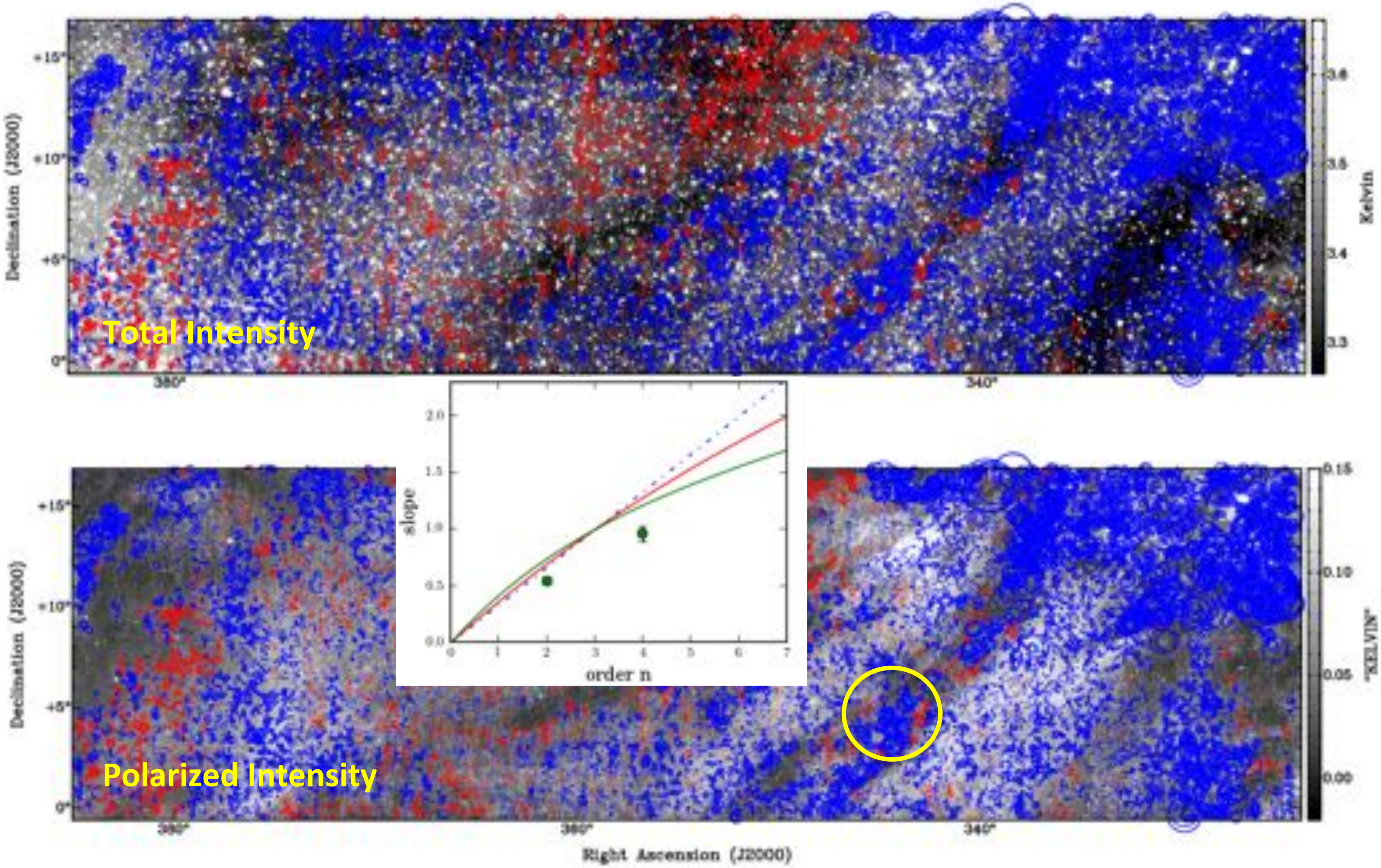


Faraday rotation of diffuse emission (GALFACTS)
Red: $\phi > 0$, blue: $\phi < 0$



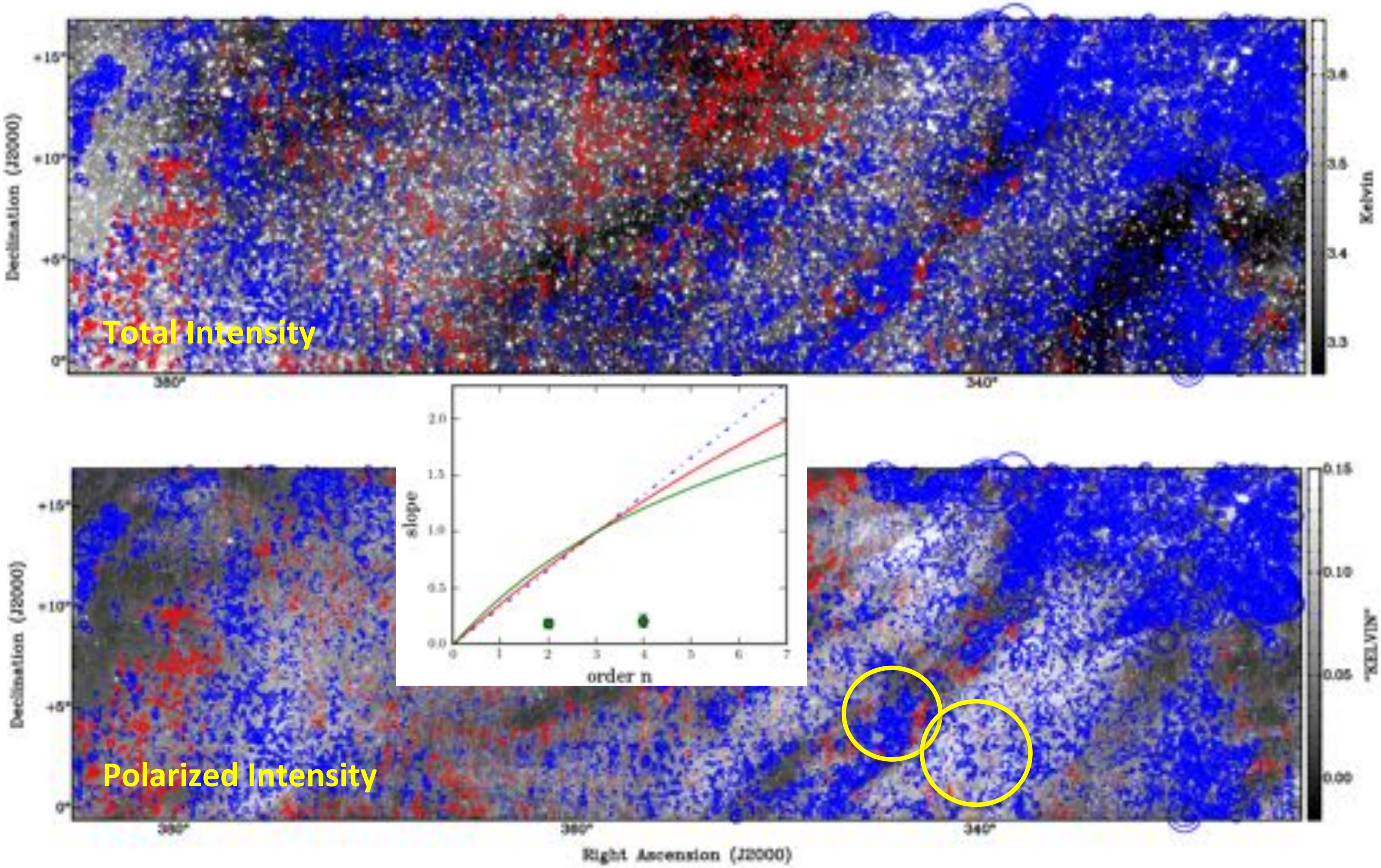


Faraday rotation of diffuse emission (GALFACTS)
Red: $\phi > 0$, blue: $\phi < 0$



Faraday rotation of diffuse emission (GALFACTS)

Red: $\phi > 0$, blue: $\phi < 0$



Conclusions

- Faraday rotation by intermediate-velocity gas provides an interesting perspective on stellar feedback and dynamo physics on small scales
- Rotation measure and emission measure can be combined to find a lower limit to the Alfven speed

$$\bar{v}_A \geq (0.820 \text{ km s}^{-1})\mu_e^{-1/2} f^{-1/4}\left(\frac{L}{100 \text{ pc}}\right)^{-1/4}\mathcal{R}^{-1}\left[\frac{|\phi|}{EM^{3/4}}\right]$$

- A long IV filament is found to have a low plasma β
- Structure functions (0.2° – 2° scale) show topology of RM fluctuations (turbulence?) is different in the filament and the surrounding synchrotron emission.

What can we derive directly from Rotation Measure and Emission Measure?

$$\phi = 2.63 \times 10^{-13} \int n_e B_{\|} dl \quad \mathrm{rad\ m}^{-2}$$ SI Units

$$\phi = 2.63 \times 10^{-13} (\mu_e\, m_p)^{1/2} \mu_0^{1/2} \int n_e^{3/2} \frac{B_{\|}}{\sqrt{\mu_0 \rho}} dl$$

$$|\phi| \leq 2.63 \times 10^{-13} (\mu_e\, m_p)^{1/2} \mu_0^{1/2} \int n_e^{3/2} \frac{|B_{\|}|}{\sqrt{\mu_0 \rho}} dl$$

$$|\phi| \leq 2.63 \times 10^{-13} (\mu_e\, m_p)^{1/2} \mu_0^{1/2} \int n_e^{3/2} \frac{|B|}{\sqrt{\mu_0 \rho}} dl$$

Recall that the Alfven velocity is $v_A = \dfrac{|B|}{\sqrt{\mu_0 \rho}}$

$$|\phi| \leq 2.63 \times 10^{-13} (\mu_e m_p)^{1/2} \mu_0^{1/2} \int n_e^{3/2} \frac{|B|}{\sqrt{\mu_0 \rho}} dl$$

$$\bar{v}_A = \frac{\int n_e^{3/2} \left(\frac{|B|}{\sqrt{\mu_0 \rho}} \right) dl}{\int n_e^{3/2} dl}$$

$$dl = L dx$$

$$\mathcal{R} \equiv \frac{\int n_e^{3/2} dx}{\left[\int n_e^2 dx \right]^{3/4}} = f^{-\frac{1}{4}} L^{-\frac{1}{4}} \frac{\int n_e^{3/2} dl}{EM^{3/4}}$$

$$\bar{v}_A \geq (0.820 \text{ km s}^{-1}) \mu_e^{-1/2} f^{-1/4} \left(\frac{L}{100 \text{ pc}} \right)^{-1/4} \mathcal{R}^{-1} \left[\frac{|\phi|}{EM^{3/4}} \right]$$