Magnetic fields in filament and bipolar bubbles using JCMT POL2 – a case study of S201

(preliminary results)

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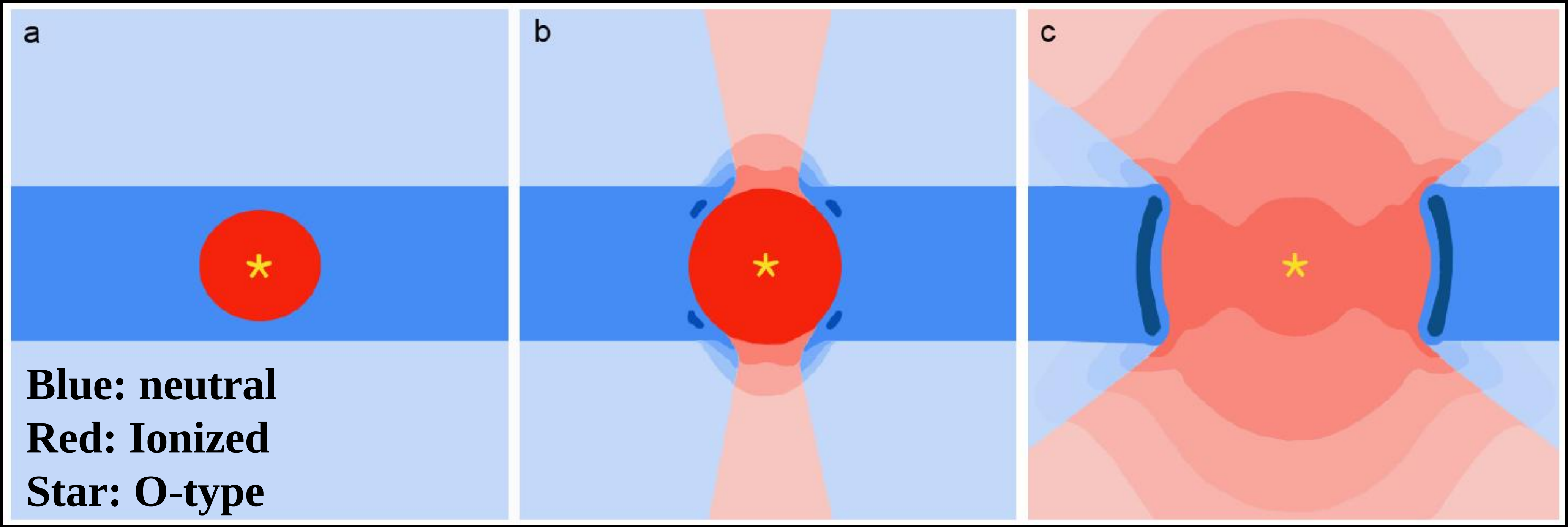
Bipolar bubbles are the natural outcome result from the anisotropic expansion of I-fronts in a filament

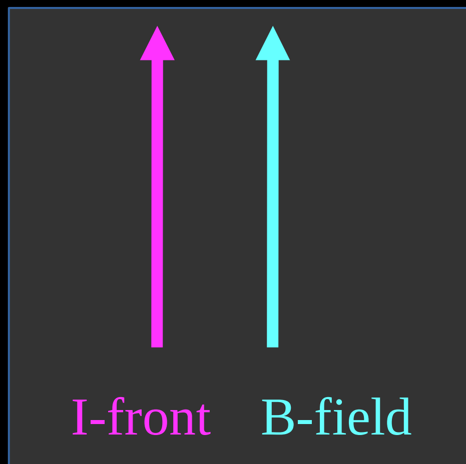


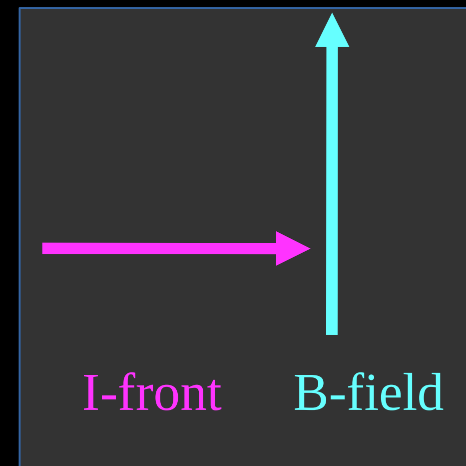
Filament => HII region => bipolar bubble
(2D HD simulations: Bodenheimer+ 1979; Deharveng+ 2015)

What is the influence of B-fields (pervading the filament) on the expansion of I-fronts and bipolar bubbles?

Influence of B-fields on expanding ionization fronts

=> Introduce anisotropic pressure





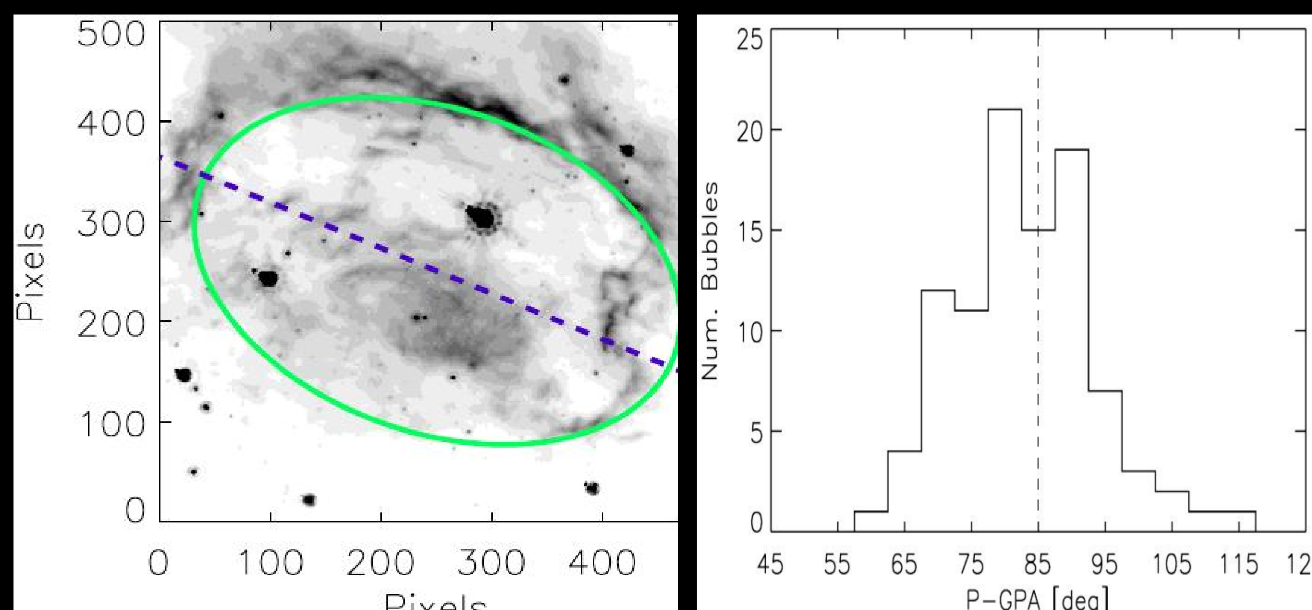
I-front ==> accelerated

==> hindered

Eg., Galactic bubbles of young HII regions elongated along the Galactic B-fields.

Easier for charged particles to follow B-fields than perpendicular to them

(Pavel & Clemens 2012)

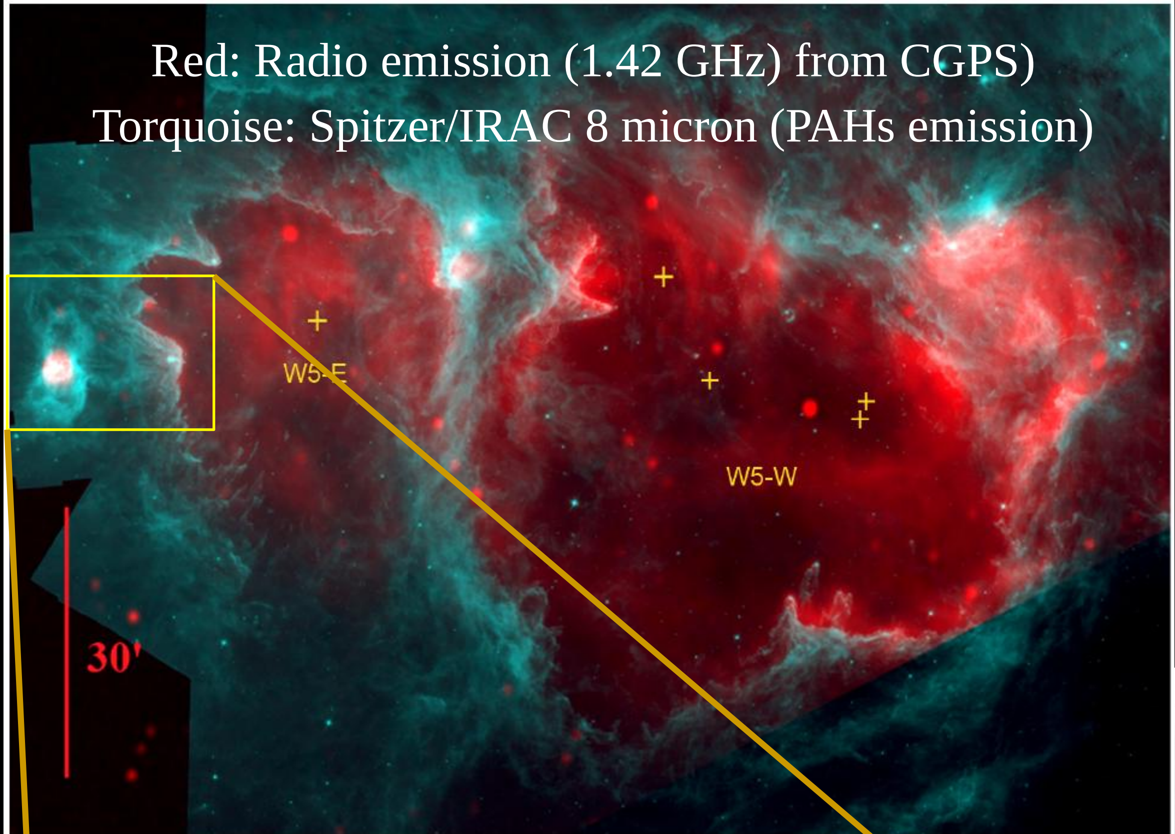


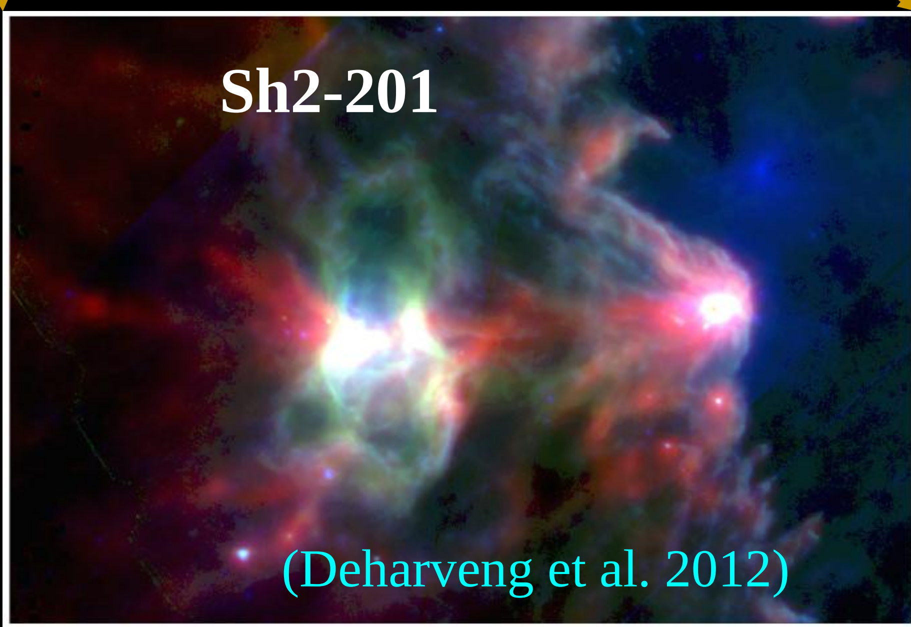
Our target: Sh201

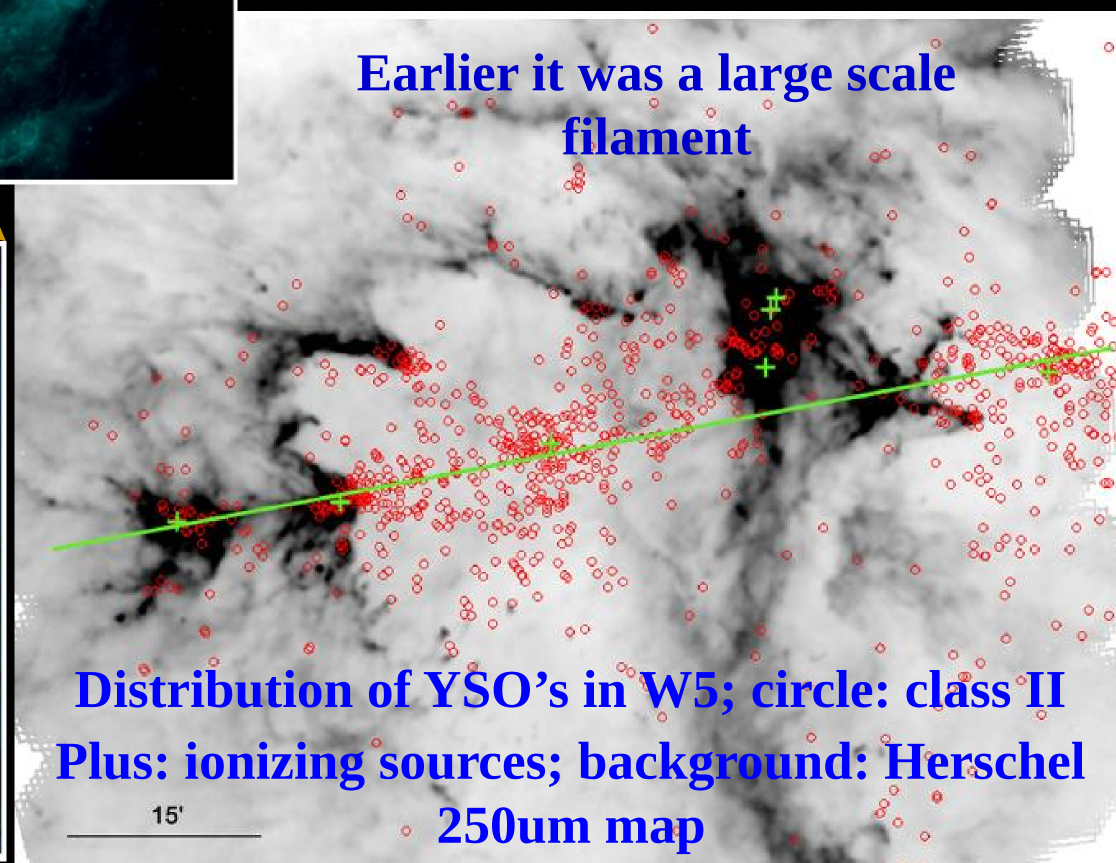
located in W5 star forming region;

Distance ~2 kpc

(Deharveng et al. 2012)







SCUBAPOL2 observations

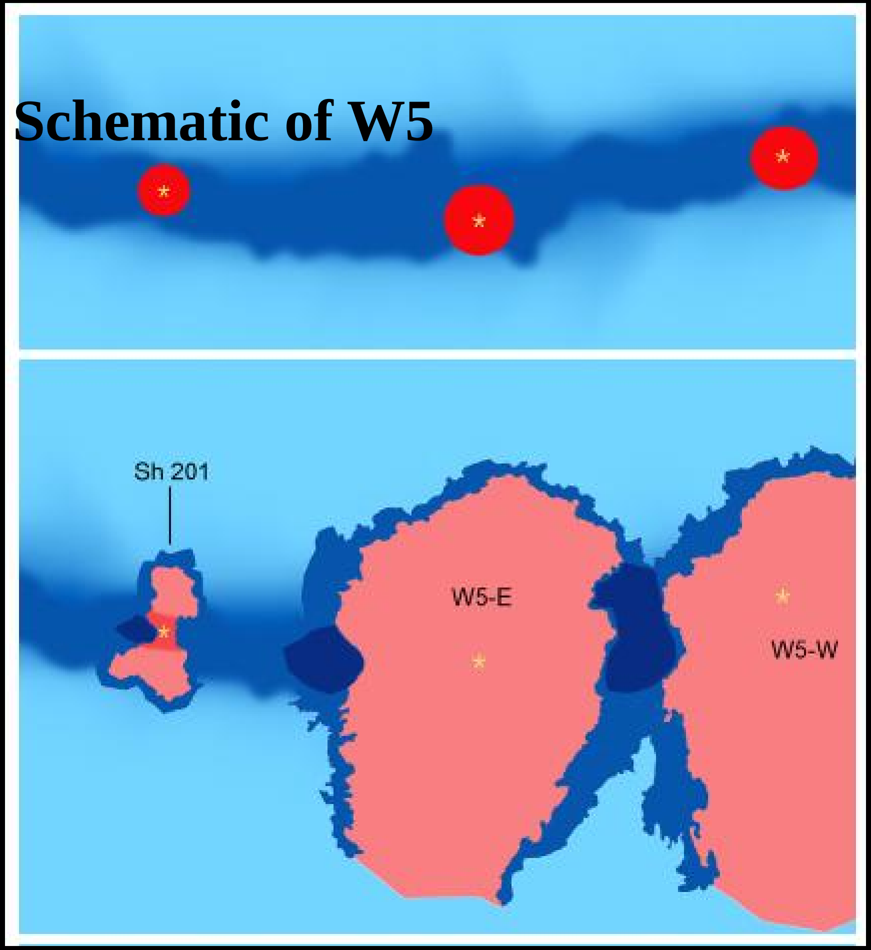
Proposal: M17BP041

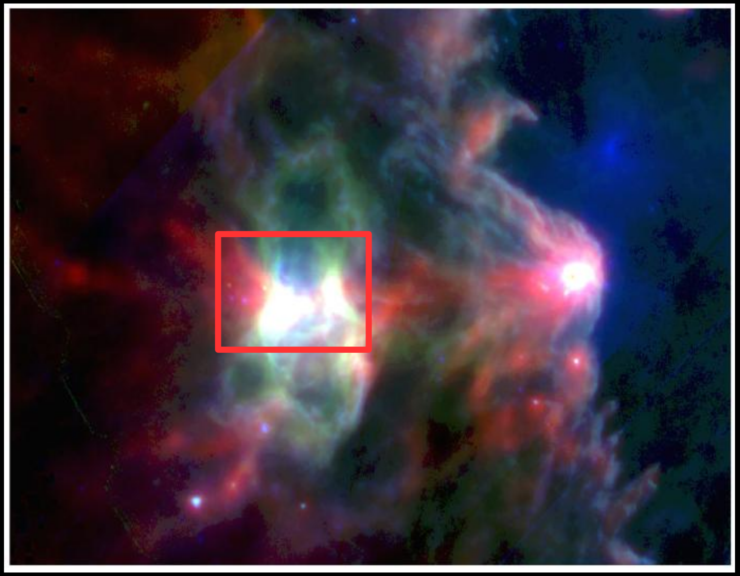
POL2 observations were acquired: 18 Nov 2017

Total time: 1.5 hrs

Total MSBs: 3 (each with 30 min)

Schematic of W5

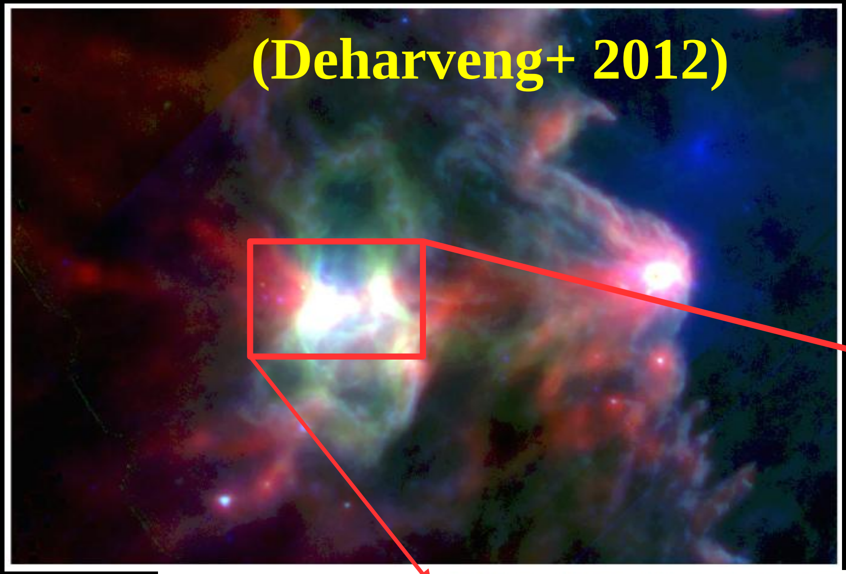


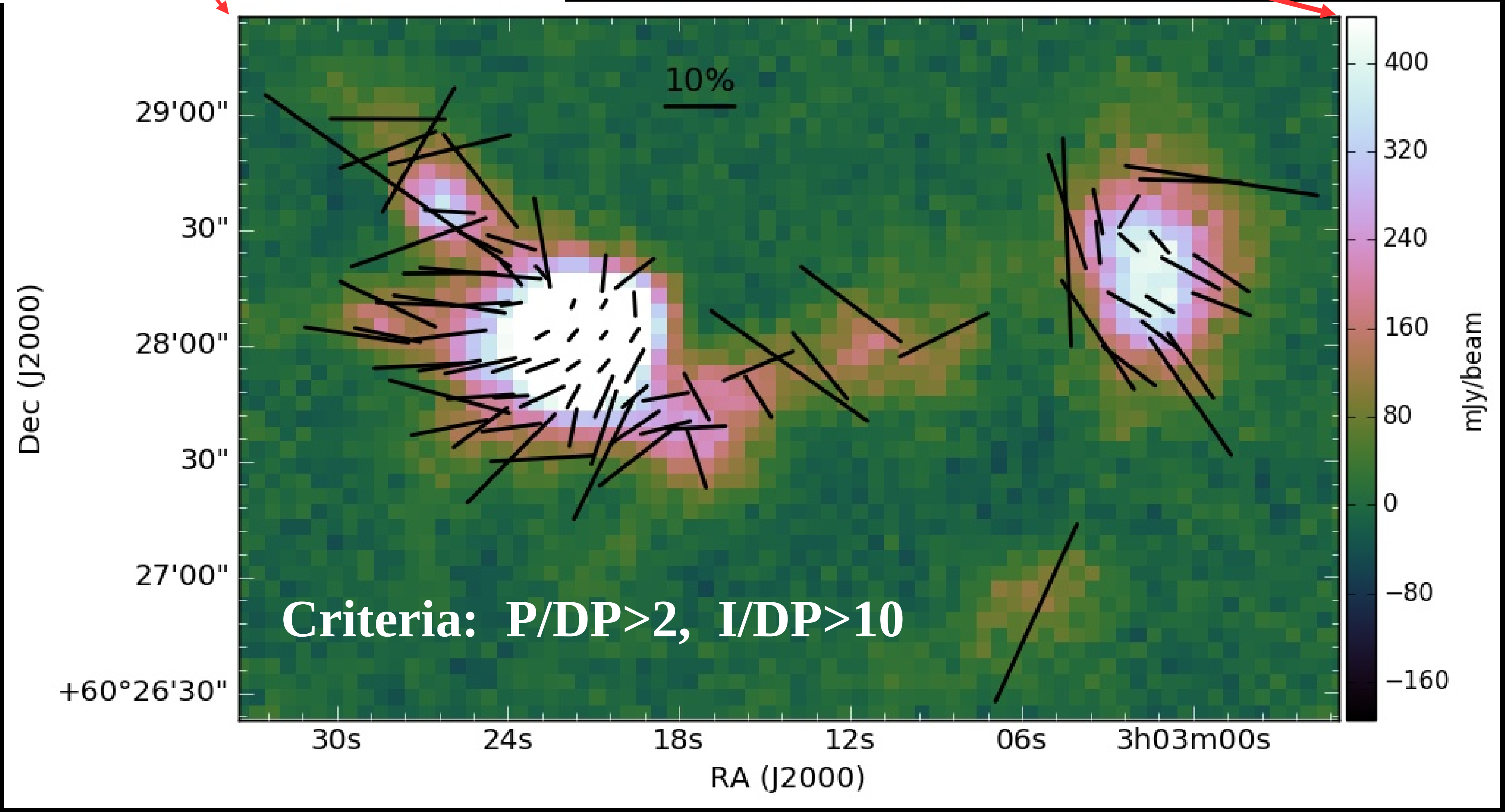


(Deharveng+ 2012)

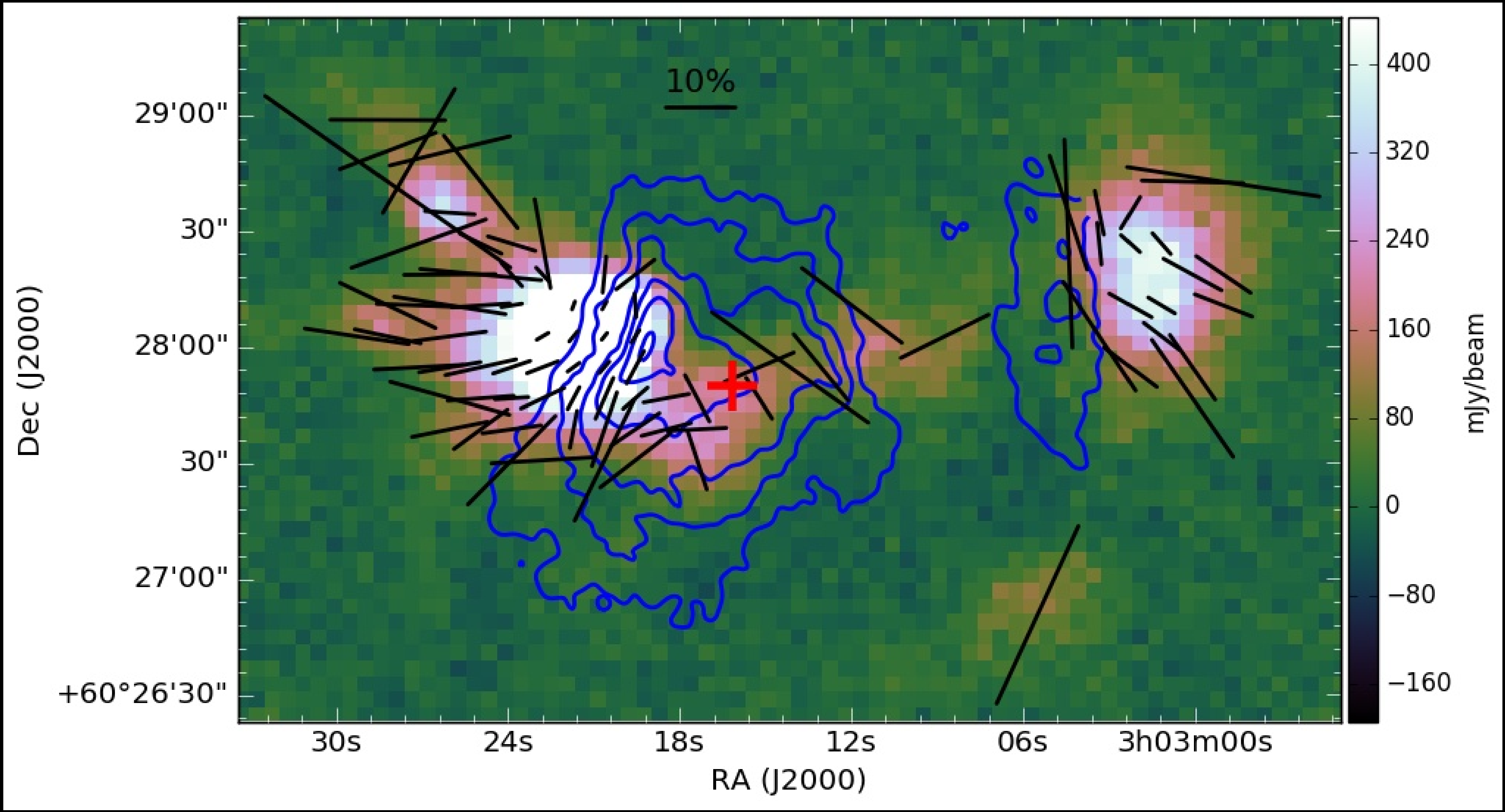
Results

B-field map in the denser parts of Sh201





B-fields exhibiting bow-like structure - shaped by the HII region

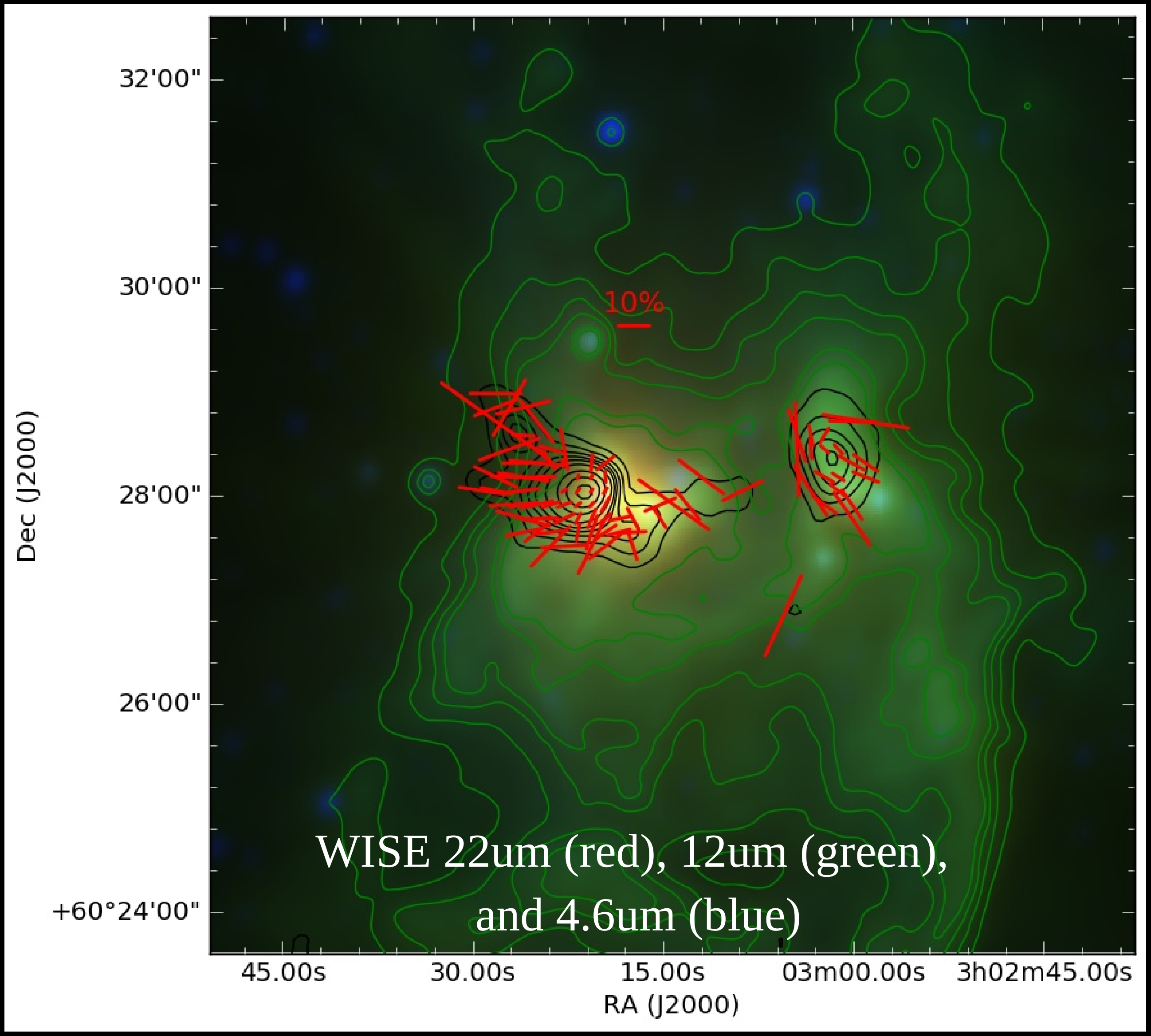


Background image: 850micron continuum – JCMT/SCUBA2

Blue contours: VLA 21 cm continuum

Plus mark: Ionizing star O6-O8 (Ojha+ 2004)

B-fields at the foot-points seem to be well connected with the bipolar structure



To understand importance of B-fields

active/passive?

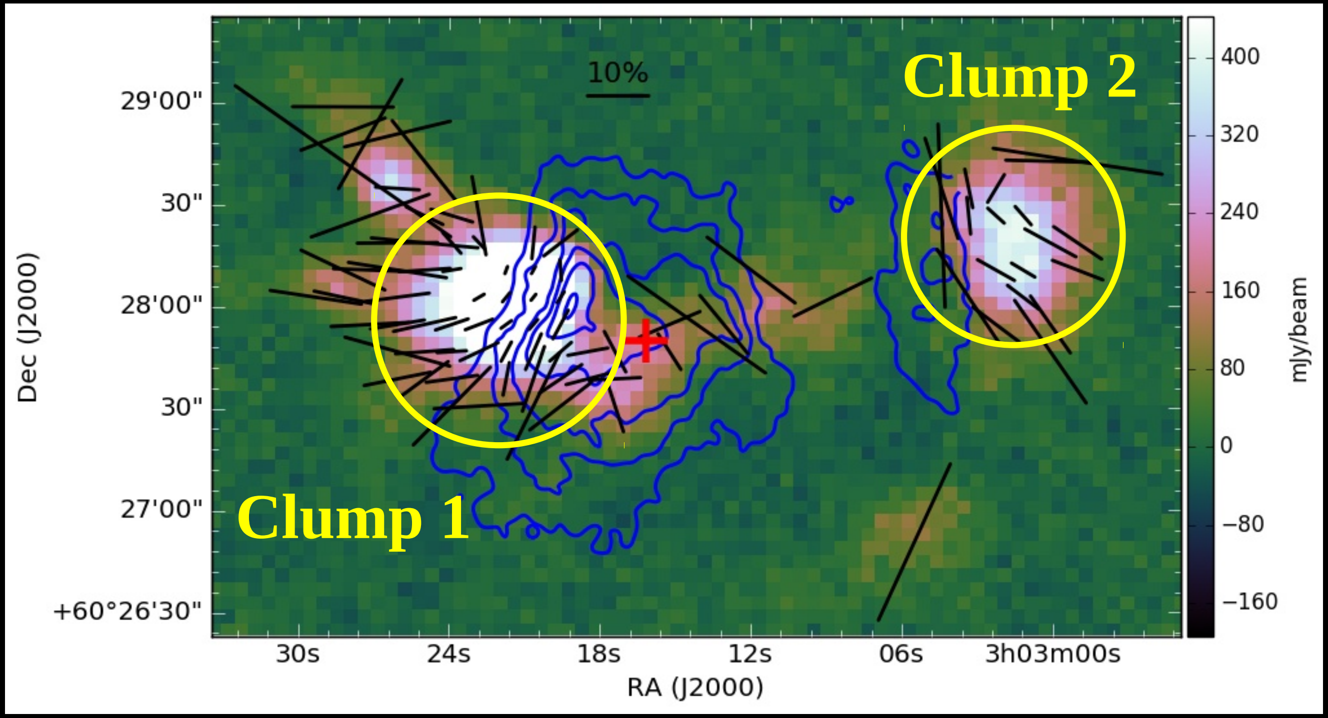
Estimate

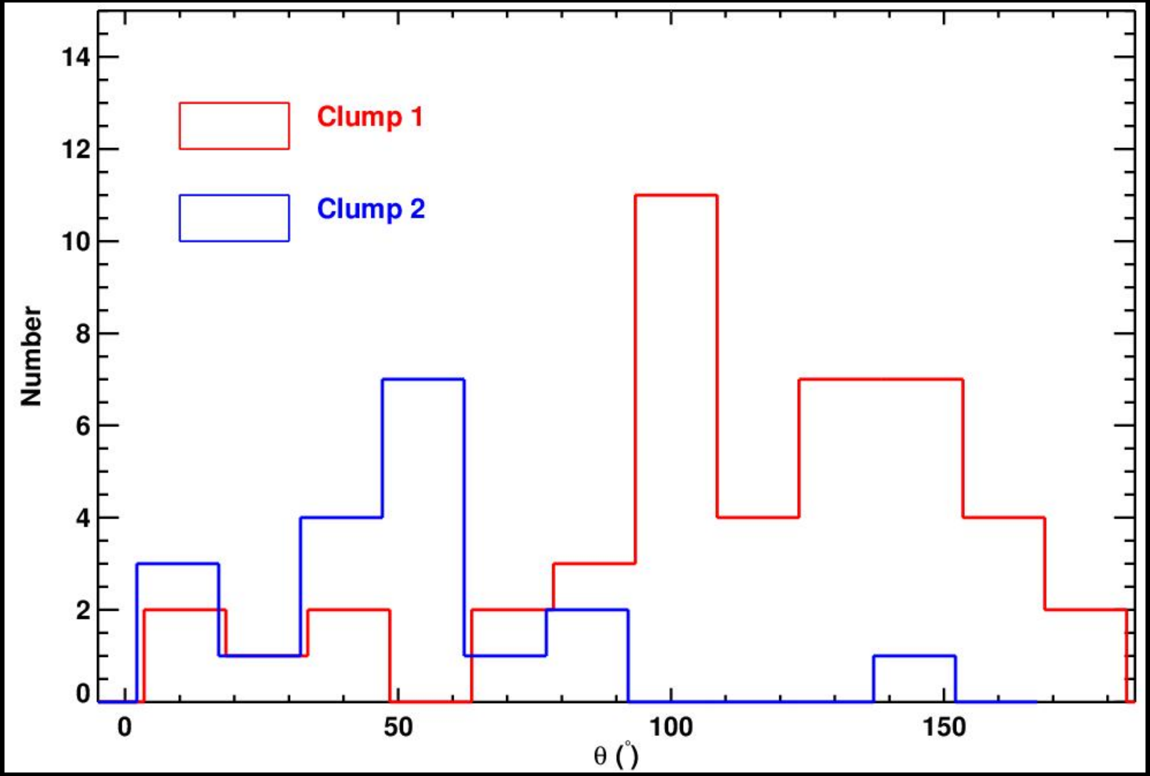
B field strength

B-field pressure

Turbulent pressure

Thermal pressure





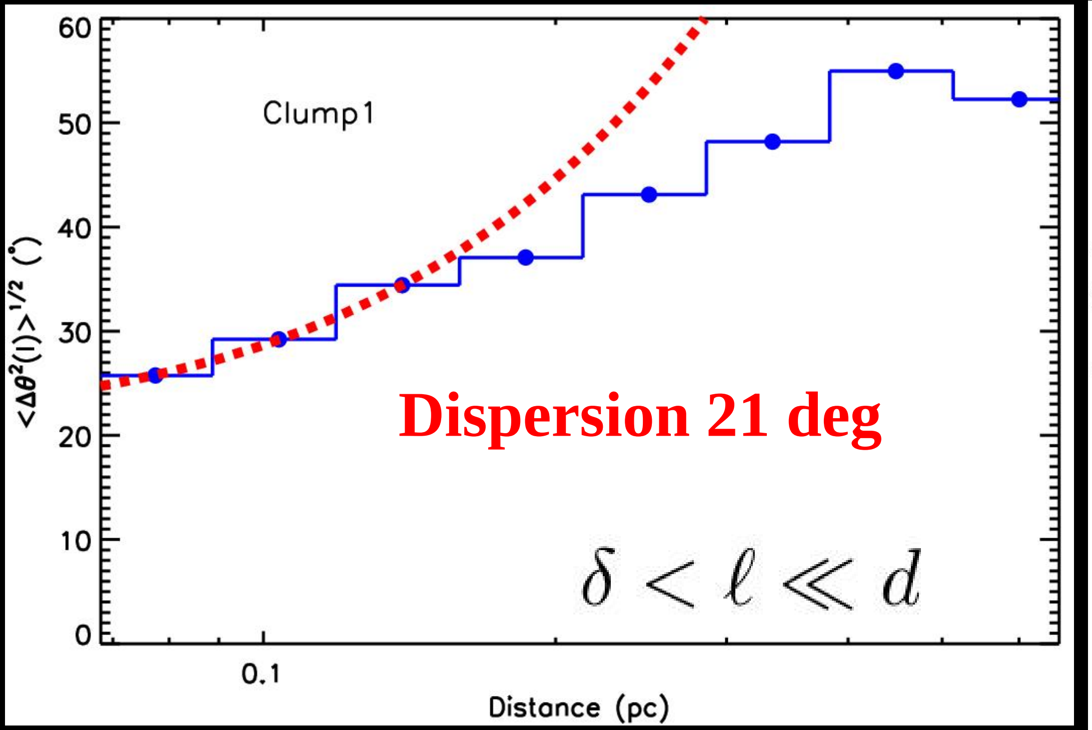
Distribution of B-fields in clump 1 & 2

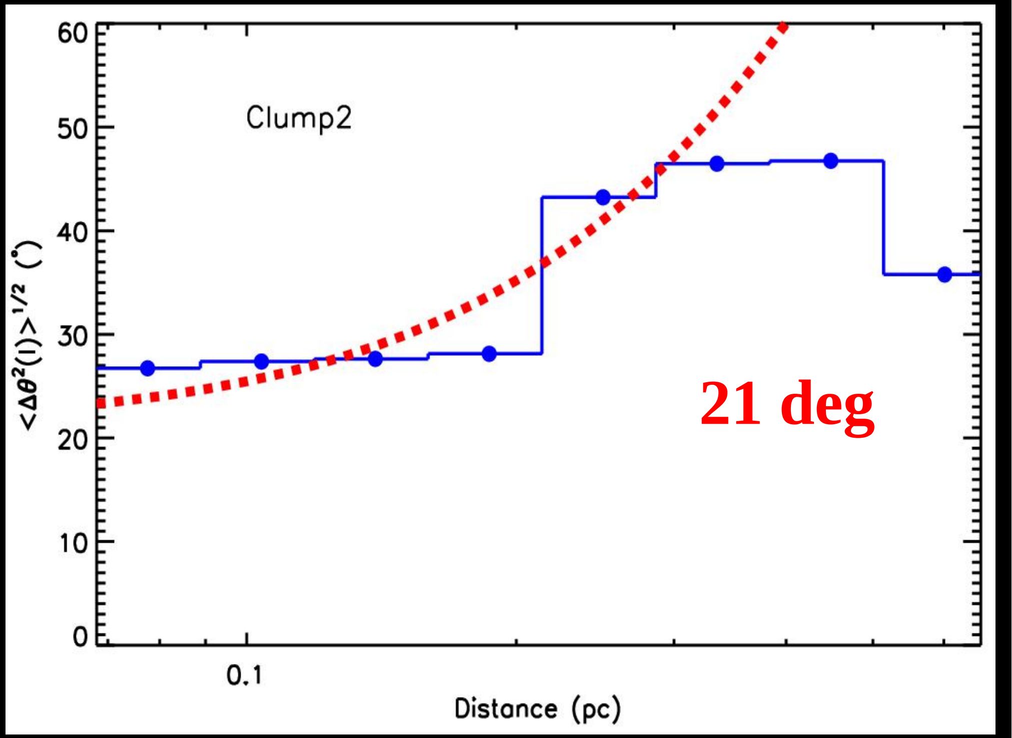
Multiple components

1) 0-50 deg

2) 100 deg

3) 150 deg





Dispersion in PA using Structure function analysis

$$\langle \Delta\Phi^2(\ell)\rangle^{1/2} \equiv \left\{ \frac{1}{N(\ell)} \sum_{i=1}^{N(\ell)} [\Phi(\mathbf{x}) - \Phi(\mathbf{x}+\boldsymbol{\ell})]^2 \right\}^{1/2}$$

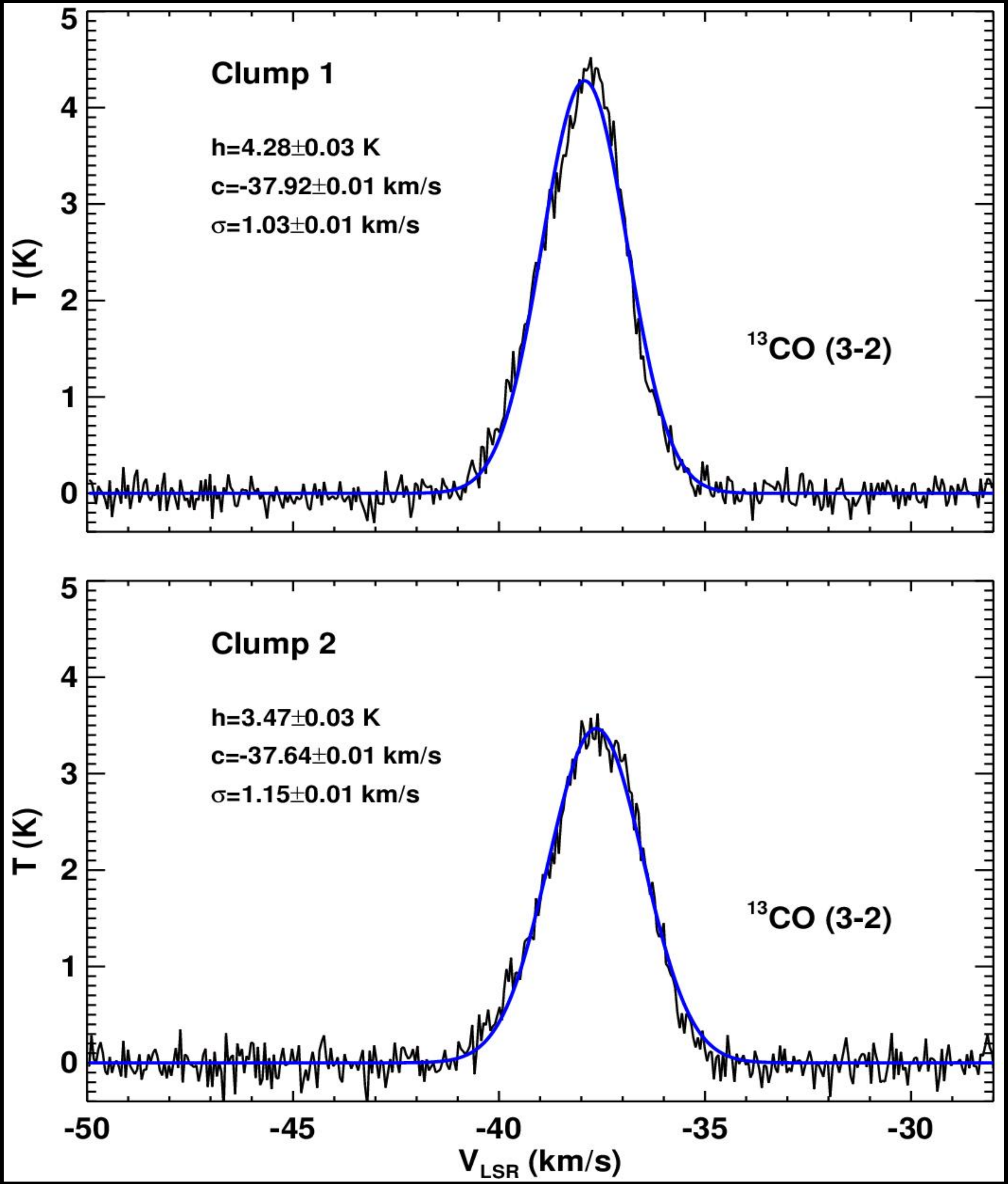
$$\frac{\langle B_t^2\rangle^{1/2}}{B_o} = \frac{b}{\sqrt{2-b^2}}$$

$$\langle \Delta\theta^2(l)\rangle_{tot} - \sigma_M^2(l) = b^2 + m^2 l^2$$

Clump1 = 0.27+0.01

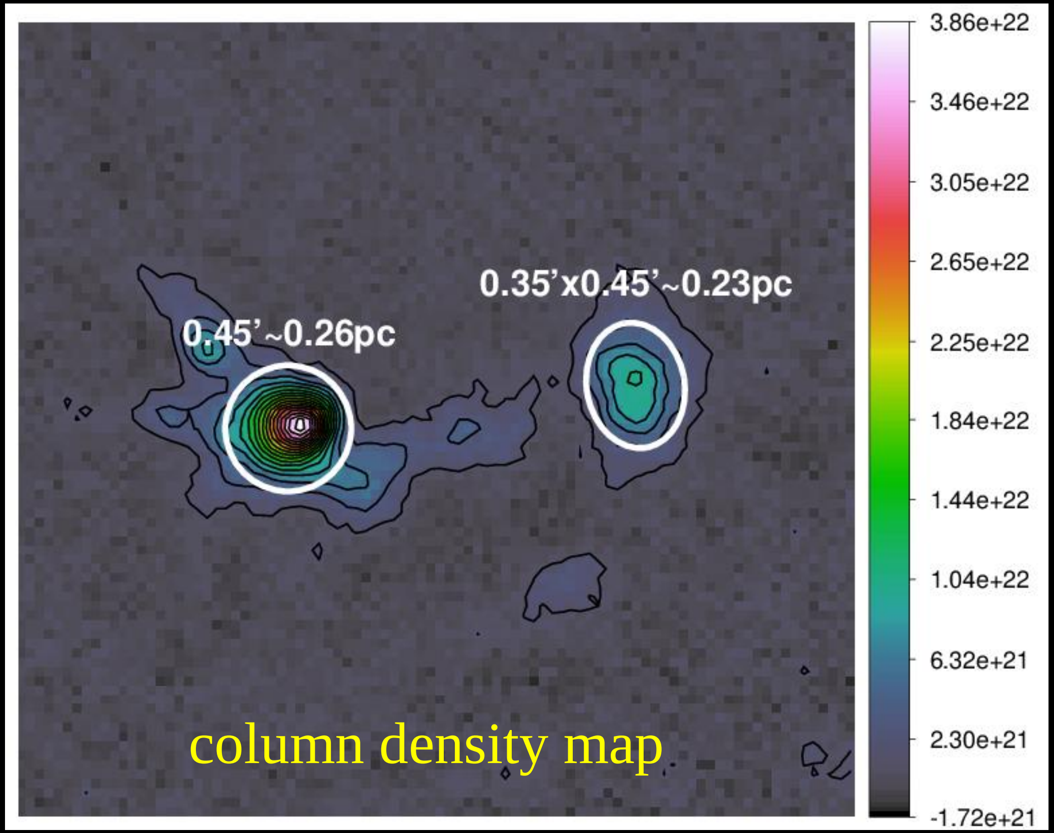
Clump2 = 0.27+/-0.06

Hildebrand+ 2009



Velocity dispersion using archival JCMT/HARP

13CO (3-2)
Clump1: 1.03 km/s
Clump2: 1.15 km/s



Number density

Column density from 850um intensity map

Number density:

n(H2)=[∑N(H2) * A]/[4/3*pi*r^3]

Clump 1: 1.22e+4 cm-3

Clump 2: 0.60e+4 cm-3

Contours: 1e+21 to ~4e+22 cm-2

$$N_{H_2} = 2.02 \cdot 10^{20}\ \mathrm{cm^{-2}} \left(e^{1.439(\lambda/\mathrm{mm})^{-1}(T/10\ \mathrm{K})^{-1}} - 1\right) \left(\frac{\kappa_\nu}{0.01\ \mathrm{cm^2\ g^{-1}}}\right)^{-1} \left(\frac{S_\nu^{\mathrm{beam}}}{\mathrm{mJy\ beam^{-1}}}\right) \left(\frac{\theta_{\mathrm{HPBW}}}{10\ \mathrm{arcsec}}\right)^{-2} \left(\frac{\lambda}{\mathrm{mm}}\right)^3$$

Instrument	λ μm	θ_{HPBW} arcsec	κ_ν cm^2 g^{-1}
SHARC	350	8.5	0.101
SCUBA	450	7	0.0619
	850	15	0.0182
BOLOCAM	1120	31	0.0114
MAMBO	1200	11	0.0102
SIMBA	1200	24	0.0102

(Kauffmann et al. 2008)

Td=26 K (Deharvang et al. 2012)

HPBW=14”

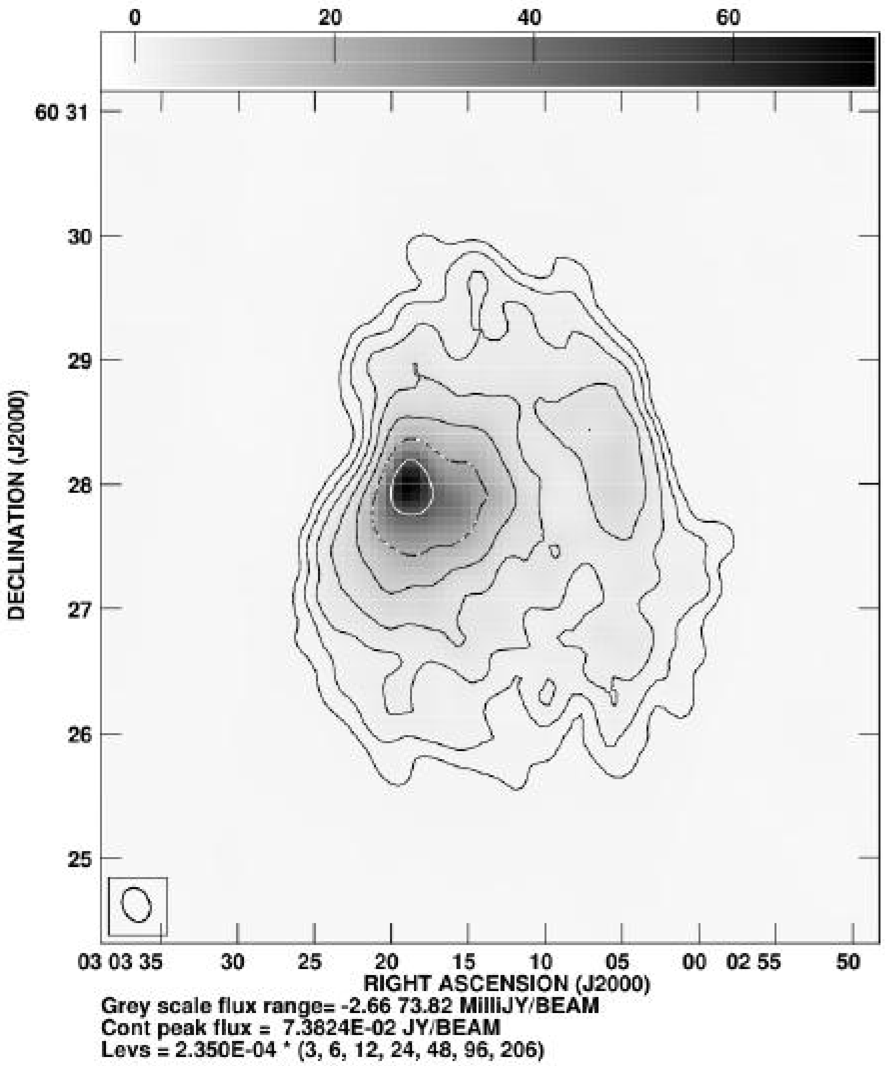


Fig. 1. Radio continuum map of S201 at 1.4 GHz. The contour levels are at 2.3E-04 × (3, 6, 12, 23, 48, 96, and 202) Jy/beam, where 2.3E-04 Jy/beam is the rms noise of the map. The beam of the map is shown in lower-left corner of the figure and is 16″× 12″.

VLA 21 cm radio map

$$n_e = \frac{4.092 \times 10^5 \mathrm{cm}^{-3}}{\sqrt{b(\nu, T_e)}} \left(\frac{S_\nu}{\mathrm{Jy}}\right)^{0.5} \left(\frac{T_e}{10^4\mathrm{K}}\right)^{0.25} \left(\frac{D}{\mathrm{kpc}}\right)^{-0.5} \left(\frac{\theta_D}{''}\right)^{-1.5} \quad (1)$$

$$S_* = \frac{7.603 \times 10^{46} \mathrm{s}^{-1}}{b(\nu, T_e)} \left(\frac{S_\nu}{\mathrm{Jy}}\right) \left(\frac{T_e}{10^4\mathrm{K}}\right)^{-0.33} \left(\frac{D}{\mathrm{kpc}}\right)^{2} \quad (2)$$

$$b(\nu, T_e) = 1 + 0.3195 \log\left(\frac{T_e}{10^4\mathrm{K}}\right) - 0.2130 \log\left(\frac{\nu}{\mathrm{GHz}}\right) \quad (3)$$

Martin-Hernandez+(2005)

Te = 8302 K (Balser+ 2011)

=7070 K (Omar 2002)

ne = 90 cm^{-3}

S_*=3.4e+47 photons/s

equivalent to O9.5V

Thermal pressure $P_t = 2\, n_e \times k_b \times T_e$

$= 20\times10^{-11}$ dyn cm^{-2}

(Eswaraiah et al. in prep)

Various parameters of two clumps of Sh201

Table 6: Various parameters of the two clumps of Sh2-201.

parameter	Clump 1	Clump 2
mean $N(H_2)$ (10^{22} cm^{-2})	1.33	0.58
radius (pc)	0.26	0.23
$n(H_2)$ ($\times 10^4$) (cm^{-3})	1.22	0.60
Mass ($M_\odot$)	64	23
$\sigma_{V_{LSR}}$ (km/s) (^{13}CO)	1.03	1.15
σ_θ (stucture function)	21	21
B-field strength (DCF) (μG)	171	131
P_B ($\times 10^{-10}$) (dyn cm^{-2})	12	7
P_{turb} ($\times 10^{-10}$) (dyn cm^{-2})	6	4
P_B/P_{turb}	2	2
P_{ther} ($\times 10^{-10}$) (dyn cm^{-2})	2	2
P_B/P_{therm}	6	3

B-field strength: $B = Q\sqrt{4\pi\rho}\left(\frac{\sigma_{V_{LSR}}}{\sigma_{\theta_H}}\right)$

B-field pressure: $P_B = B^2/8\pi$

Turbulent pressure: $P_{\rm turb} = \rho\sigma_{\rm turb}{}^2$

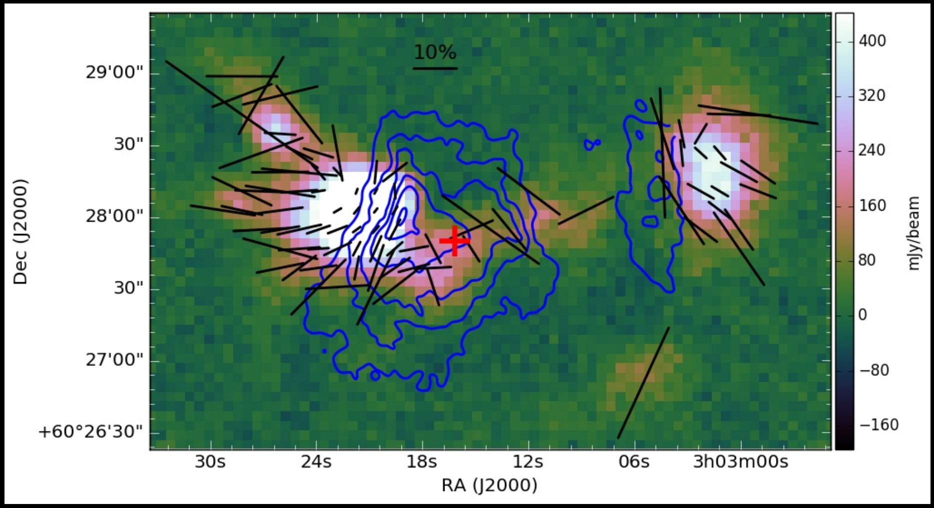
Thermal pressure: $P_{ther} \simeq 2n_e k T_e$.

Magnetic pressure > Turbulent pressure

Magnetic pressure > Thermal pressure

(Eswaraiah et al. in prep)

Summary



B-fields

- Traced at the dense clumps (foot points) in the filament of S201
- Strong enough to redirect the expanding I-fronts
- Active (rather than being passive)
- Introduce aniosotropy on expanding I-fronts to form bipolar bubbles

Need to be done

- Compare observed B-field map with RMHD models
  (Mackey & Lim 2011a, 2011b, 2013)
- Polarization vs. Intensity relations, comparison with other regions
- Comparison among the gradients of Intensity, Velocity, and B-fields
- Comparisons among clump/core geometry with B-fields