The magnetic field structure in the Rosette massive star forming region

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Milky Way's magnetic fingerprint

Outline

- ⋆ Introduction
  Why are massive star forming regions interesting and why do we want to understand their magnetic field structure?

- ⋆ Model
  An analytical solution of the magnetic field in a spherical bubble-shell structure

- ⋆ Observations
  Polarized dust emission from *Planck* and radio rotation measures towards the Rosette nebula, the canonical massive star forming region

- ⋆ Summary

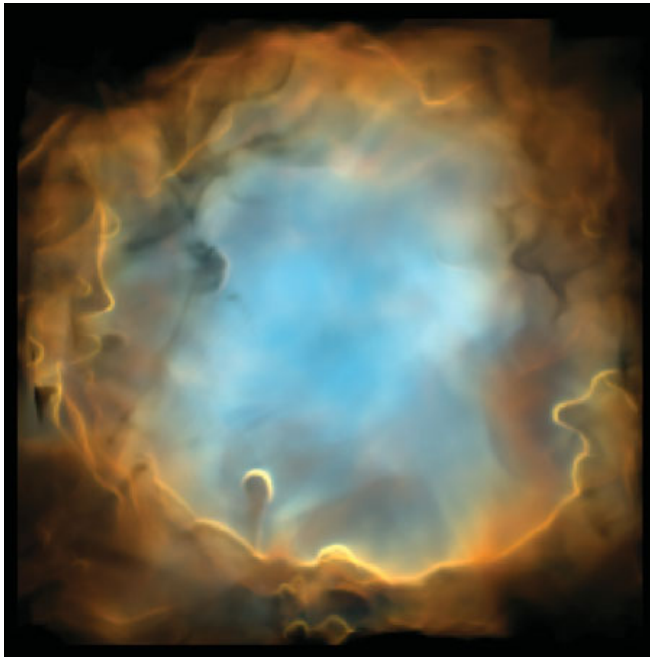
Introduction

Massive stars are the main sources of **turbulent energy** injection in the interstellar medium (ISM):

- ★ Powerful stellar winds
- ★ HII (ionized) regions
- ★ Supernovae

The surrounding ISM is swept up into a dense shell → interstellar bubble

What are the effects of massive star formation and feedback on the **structure of the magnetic field**?



Simulation by Arthur et al. (2011)
Blue [OIII], green [Hα], red [NII]

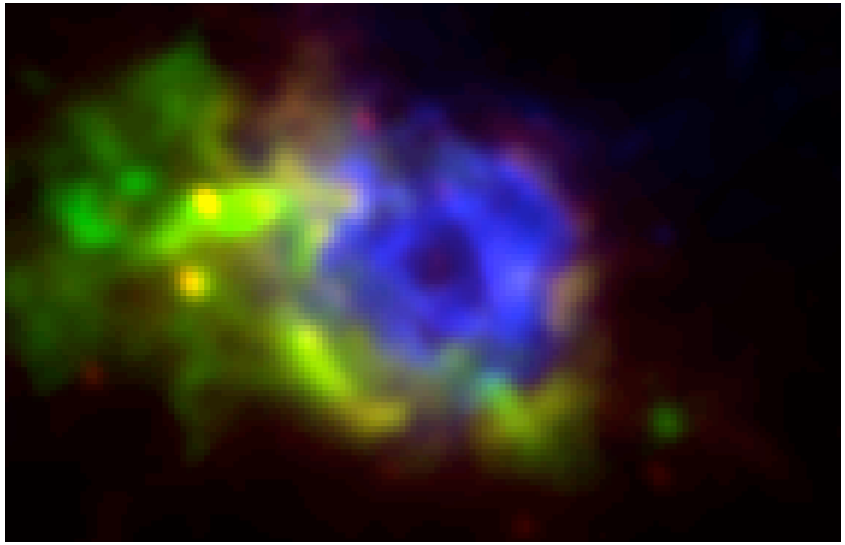
Studies of ***B*** structure in massive star forming regions:

- using high resolution dust polarization in emission and extinction restricted to small regions of the sky (e.g., Zeng 2013, Santos et al. 2014)
- using rotation measure observations (e.g. Harvey-Smith et al. 2011, Savage et al. 2013)
- analytical and numerical (e.g., Ferrière et al. 1991, Krumholz et al. 2007, Arthur et al. 2011)

Introduction

Planck provides the first all-sky map of dust polarized emission, which we can use to study the magnetic field as traced by interstellar matter (F. Levrier's talk)

Combine *Planck* polarization data with radio rotation measure observations to study the magnetic field structure in the nebula

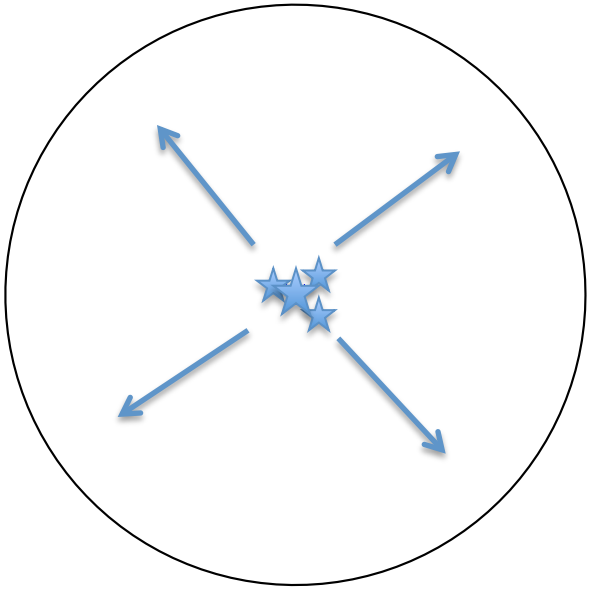


The Rosette nebula and its parent molecular cloud: IRAS 12μm (red), *Planck* 353 GHz (green), SHASSA Hα (blue)

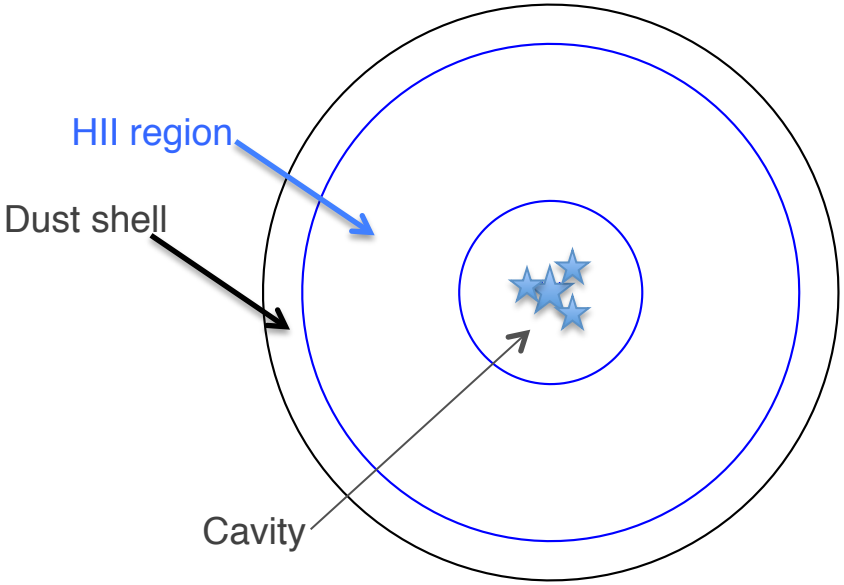
We develop an analytical description of the magnetic field in a spherical bubble-shell structure and use it to reproduce the sub-mm and radio observations consistently

Model: The magnetized Strömgren shell

- Massive stars form and ionize the surrounding gas up to the Strömgren radius: HII region
- The ionized gas starts expanding in response to an increase in pressure
- This expansion sweeps up the surrounding ISM into a shell, formed around the HII region
- Frozen-in condition: the **magnetic field** lines are **dragged** with the expanding gas



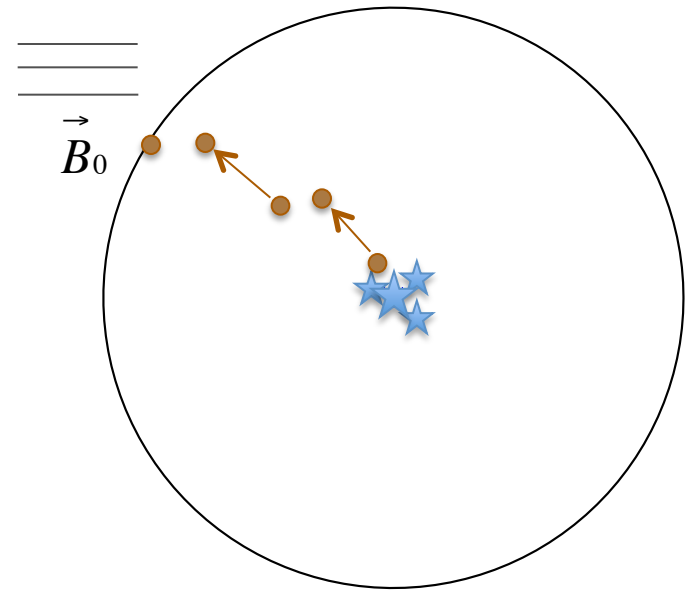
The change in the initial magnetic field structure is due to a change in the distribution of matter



Model: The magnetized Strömgren shell

Derive an analytical description of the radial expansion of matter in a uniform and spherical structure (conservation of mass):

$$r_{final} = f(r_{initial})$$



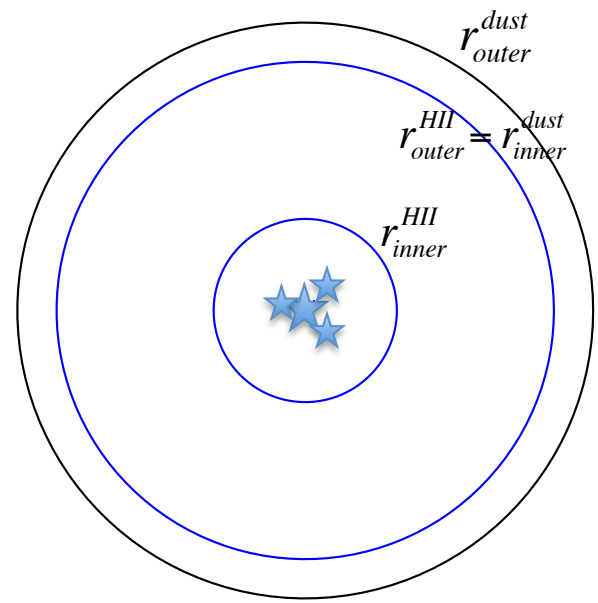
Start from a uniform magnetic B_0 field and modify it according to the radial displacement law (Parker 1970):

$$B = g(B_0, \theta_0, \phi_0)$$

Azimuthal angle (plane-of-the-sky B_0 orientation)

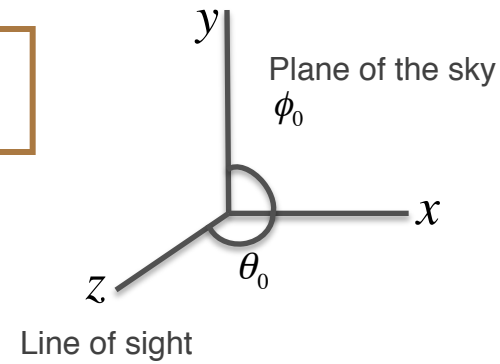
Polar angle (between B_0 and the line of sight)

Initial field strength - field in the parent molecular cloud

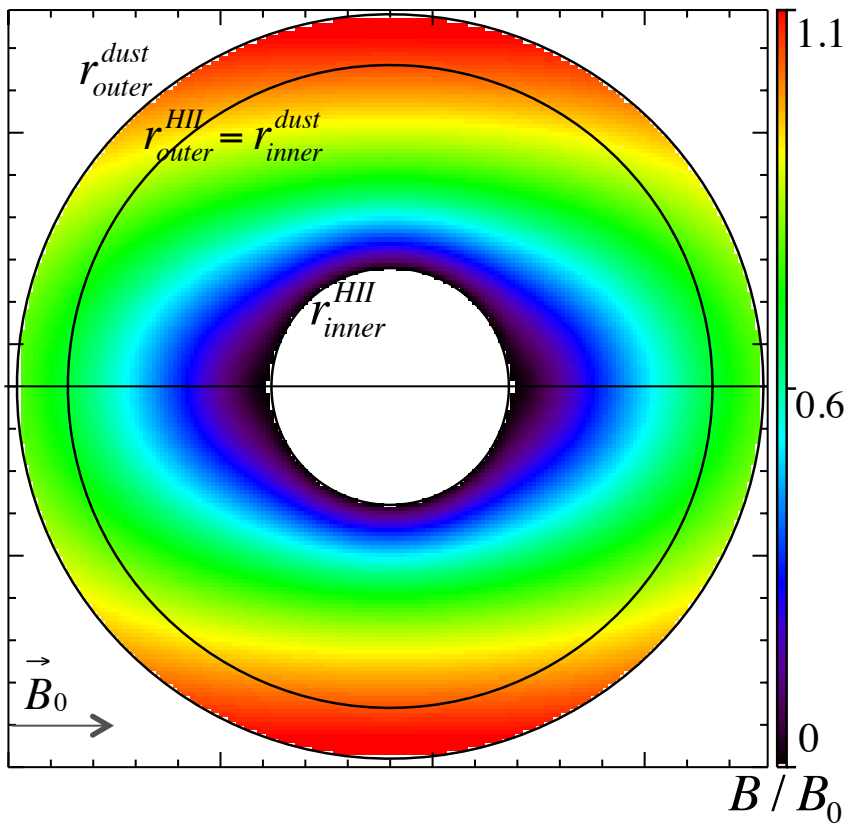


Model: Magnetic field compression?

The displacement law defines where the magnetic field is compressed and where the field lines are pulled apart



Slice through the centre of the shell, in the plane of the sky (xy plane)



The field is most compressed in the direction perpendicular to $\vec{B}_0$

Along $\vec{B}_0$ the field strength decreases radially towards the cavity due to magnetic flux conservation

→ Axial symmetry

$$\vec{B}_0 = B_0 \vec{e}_x$$
$$\theta_0 = 90^\circ$$
$$\phi_0 = 0^\circ$$
$$r_{final} \propto r_{initial}^{0.9}$$
$$\Delta r^{HII} = 0.6 r_{outer}^{HII}$$
$$\Delta r^{dust} = 0.1 r_{outer}^{dust}$$

Model: reproducing the observables

Stokes parameters of dust polarized emission: we consider a uniform medium with constant dust alignment efficiency p_0

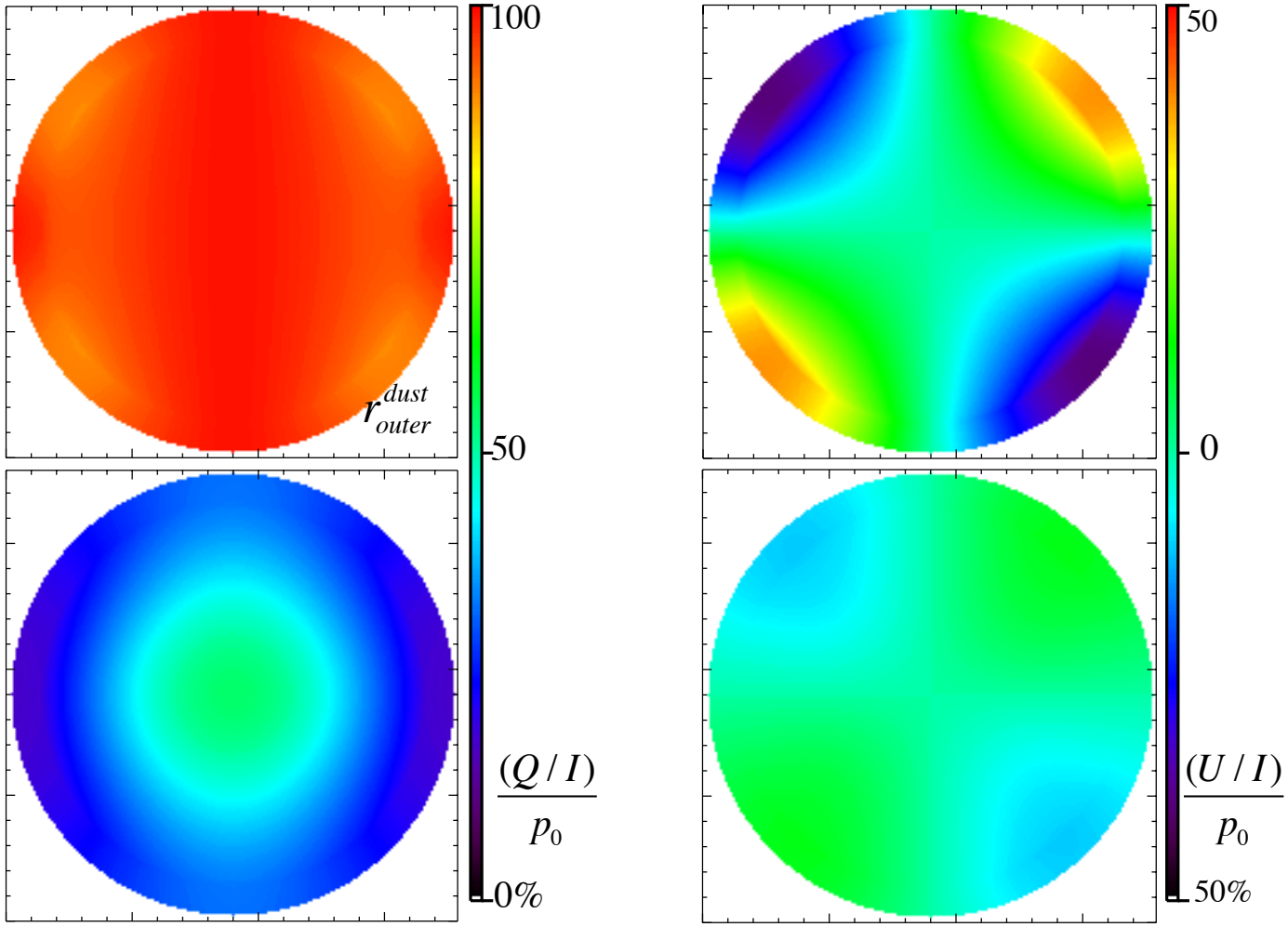
$$Q/I = p_0 \cos(2\phi)^2 (1 - \sin^2(\theta)) \qquad U/I = p_0 \sin(2\phi)^2 (1 - \sin^2(\theta))$$

$\theta_0 = 90^\circ$

$\phi_0 = 0^\circ$

$\theta_0 = 35^\circ$

$\phi_0 = 0^\circ$



Poster by D. Arzoumanian

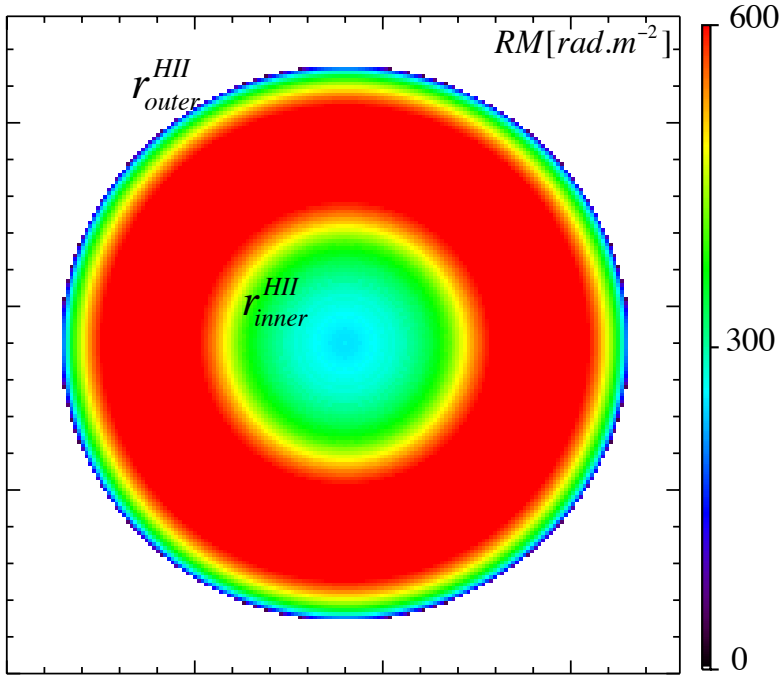
Model: reproducing the observables

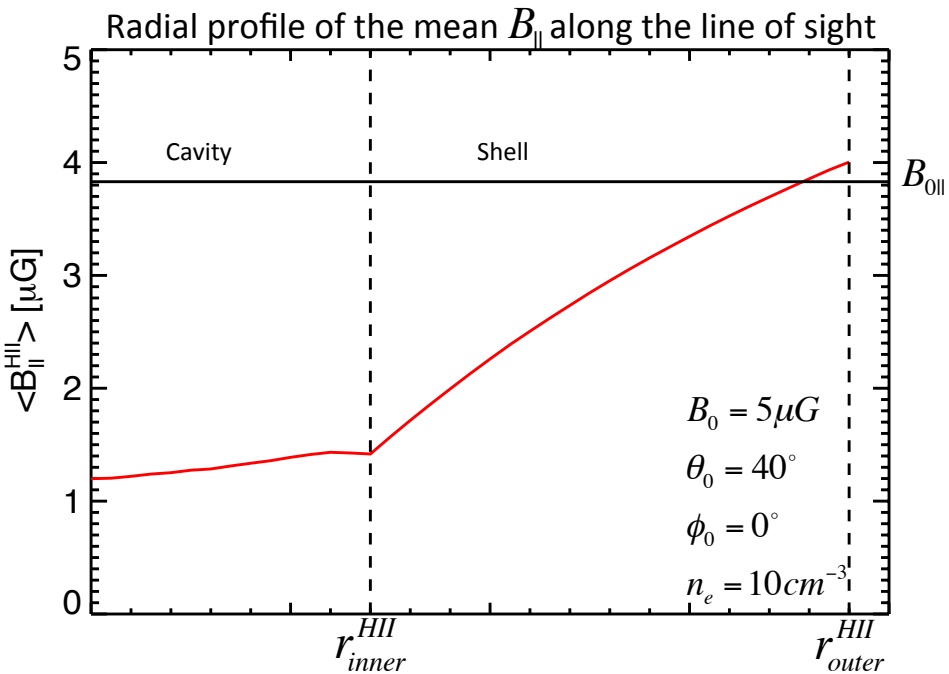
Faraday rotation – rotation measure: rotation of the plane of polarization of a background radio emission by free electrons and thus occurs in the HII (ionized) region

$$RM = \frac{d\chi}{d\lambda^2} = \frac{e^3}{2\pi m_e^2 c^4} \int_S^0 B_{\parallel} n_e \, ds$$

Line-of-sight component of the field $B_{\parallel}$
Electron density n_e

We consider a uniform electron density distribution and integrate $B_{\parallel}$ along the line of sight

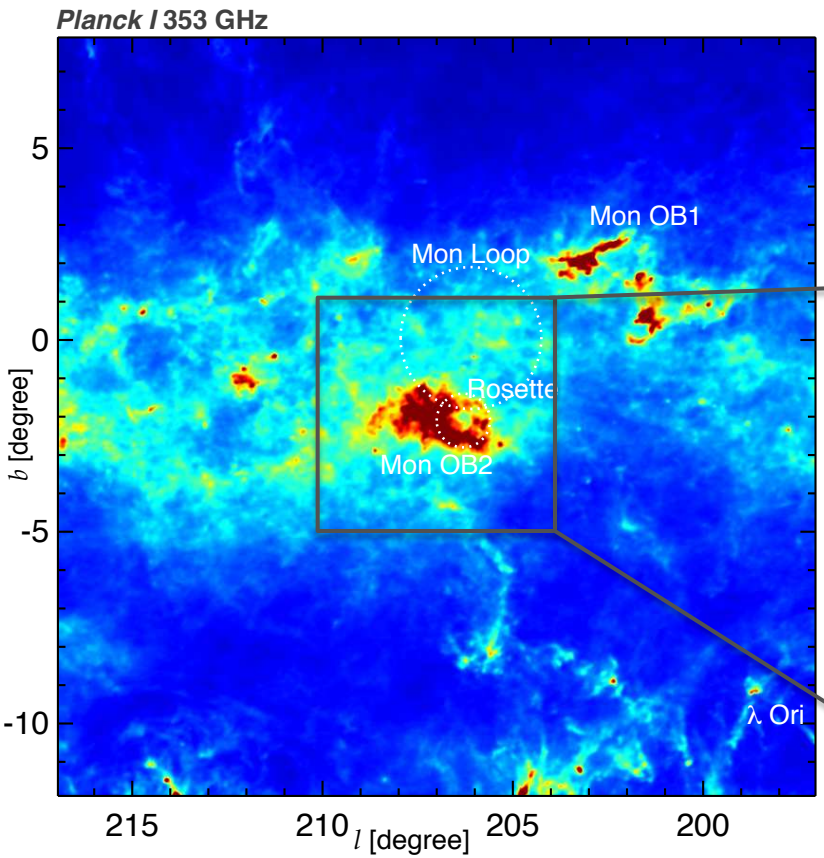


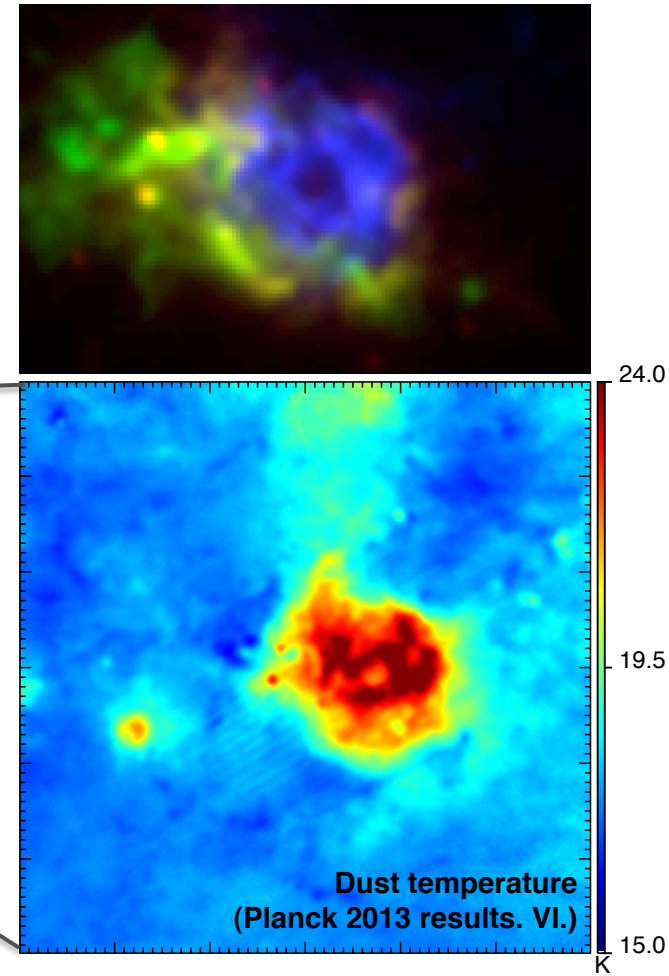


The Rosette nebula and the Mon OB2 molecular cloud

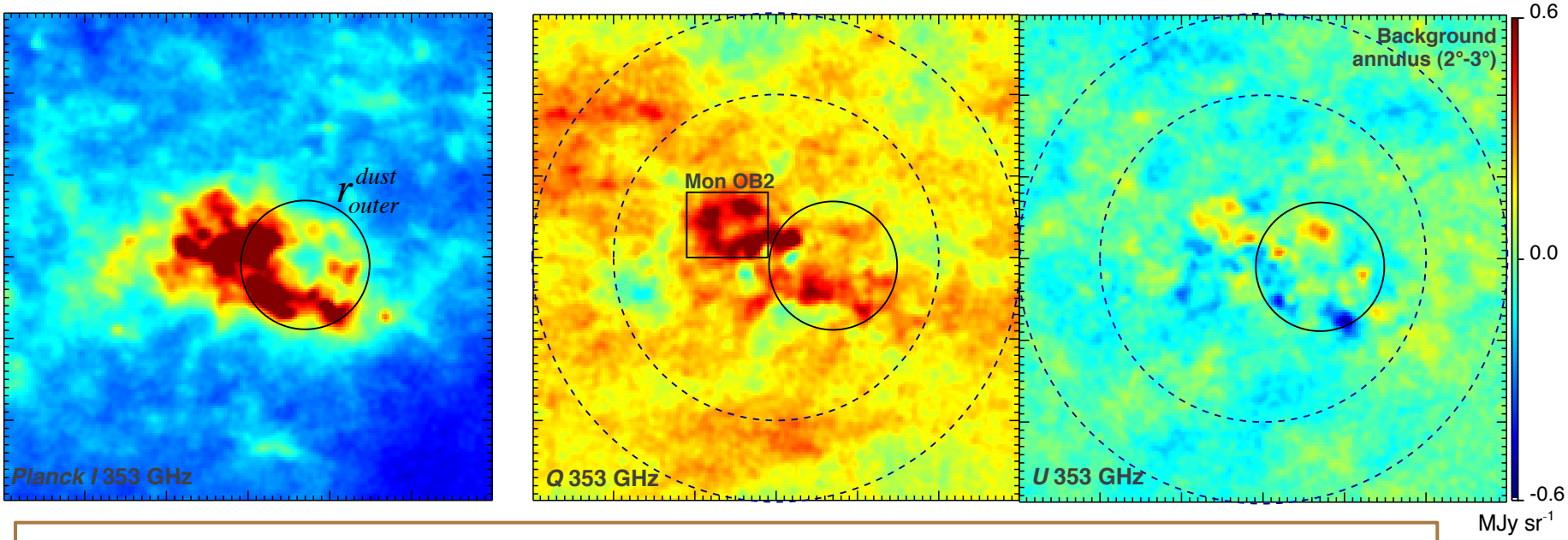
Rosette HII region is powered by the OB cluster NGC2244, formed in the Mon OB2 cloud at $d = 1.6 kpc$

- The HII region is close to a spherical shell with $r_{inner}^{HII} = 7 pc$, $r_{outer}^{HII} = 19 pc$ and $M_{HII} = 1.4 \times 10^4 M_{Sun}$
- The dust shell is seen in the *Planck* map with $r_{outer}^{dust} = 22 pc$ and has $M_{dust} = 8.6 \times 10^4 M_{Sun}$ (Heyer et al. 2006)
- From mass conservation → displacement law





Observations: *Planck* Stokes parameters

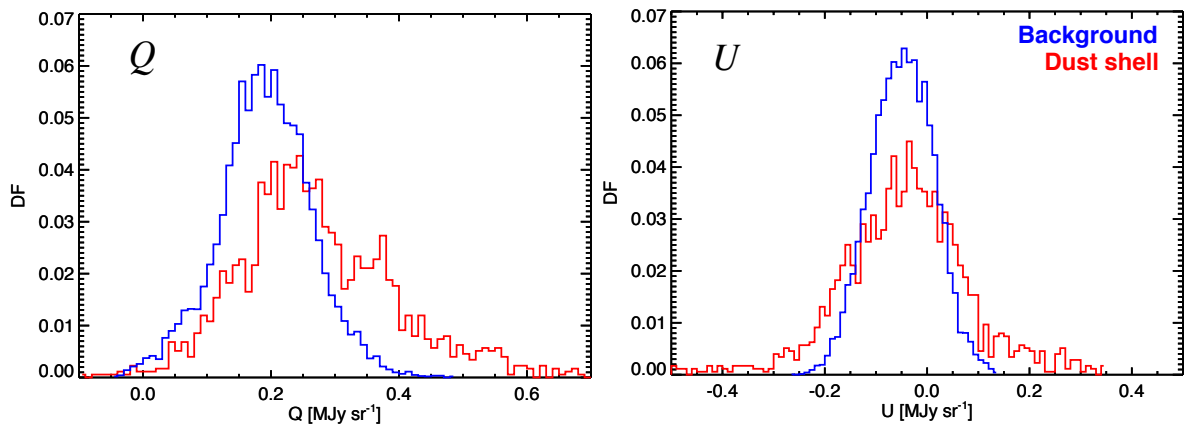


The polarized emission does not define the same shell as seen in intensity; there is significant emission outside the Rosette complex ("background")

→ We tested the **statistical difference** between shell and background when considering the **shell as a whole**

There is significant *Q* emission towards Mon OB2, where

$$p = \sqrt{(Q^2 + U^2)/I} = (4 \pm 1)\%$$



Comparison with observations: *Planck* Stokes parameters

We compare the ratio of the mean Stokes parameters *Q/I* and *U/I* measured within the dust shell that surrounds the Rosette HII region.

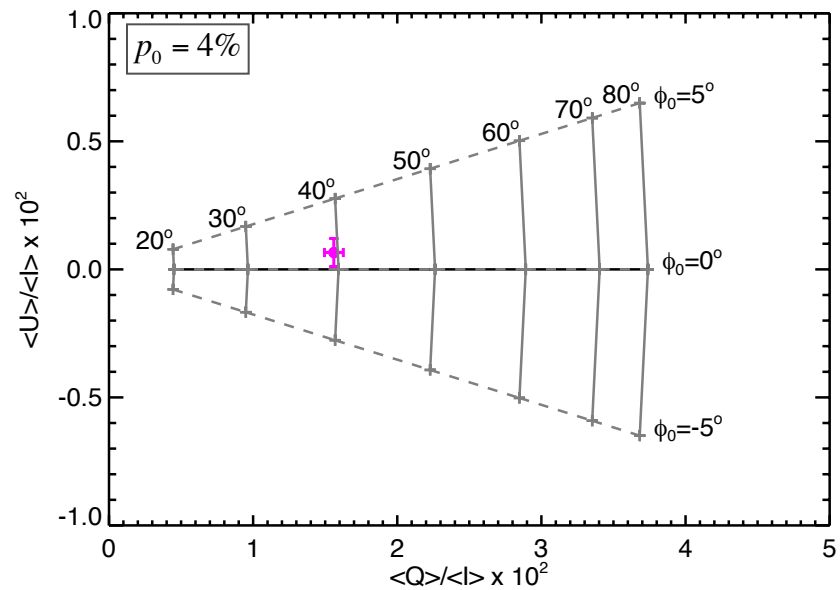
For constant density, temperature, and alignment efficiency of the dust:

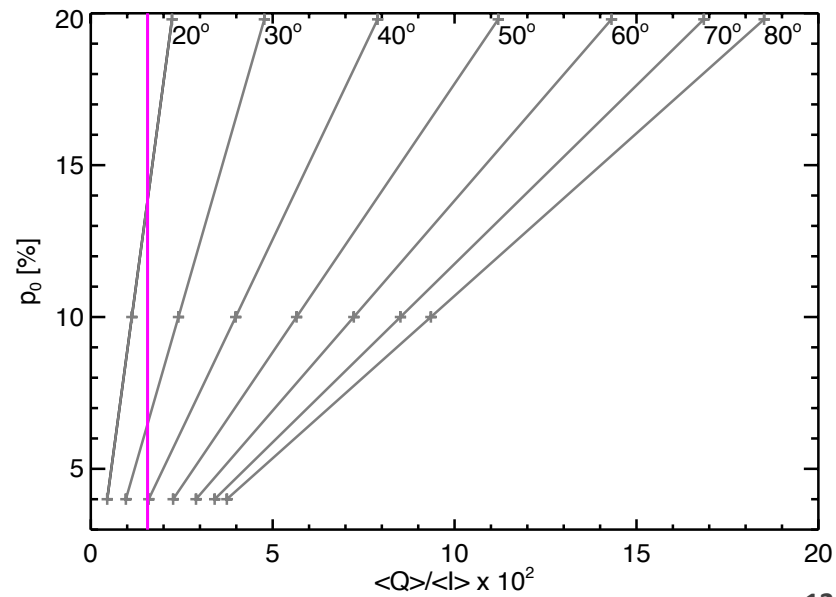
- The Stokes parameters only depend on the geometry of $\vec{B}_0$ (and not on its strength)
- The ratio <*U*>/<*I*> constrains the plane-of-the-sky orientation of $\vec{B}_0$

$\phi_0 \approx 0^\circ$ → along the Galactic plane (x axis)

- The ratio <*Q*>/<*I*> yields, for $p_0 = 4\%$ (the polarization fraction of the Rosette's parent molecular cloud) an upper limit of $\theta_0 \approx 40^\circ$

B_0 is at most 40° from the line of sight

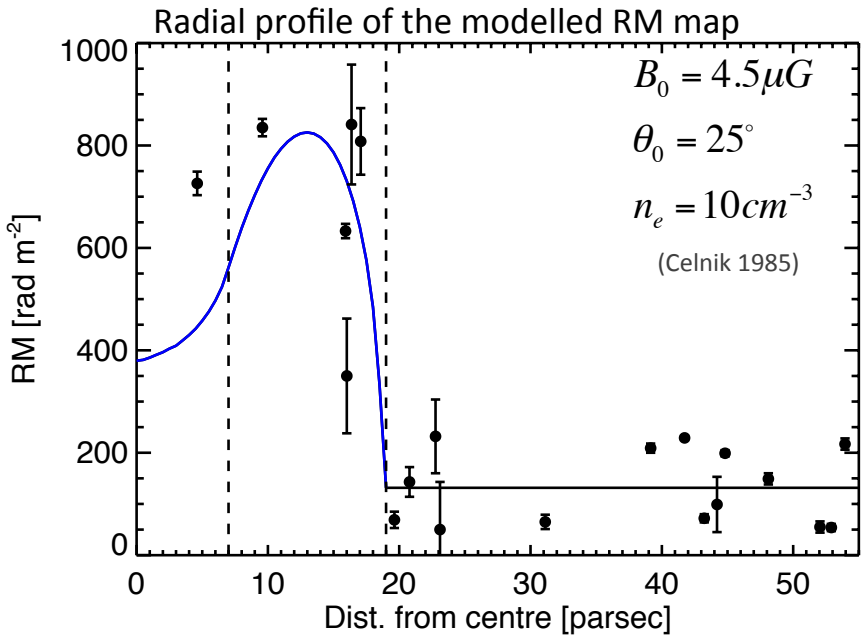


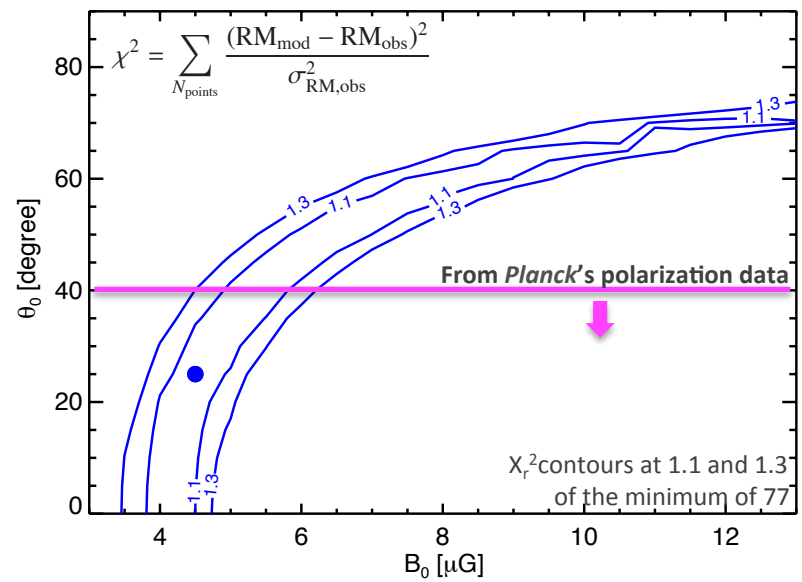


Comparison with observations: rotation measures

We use the RM data from Savage et al. (2013):
6 measurements towards the Rosette HII region and 14 outside ($r > r_{outer}^{HII} = 19\,pc$)

$$RM \propto B_{\parallel} = B\cos(\theta)$$





RM scatter can be due to non-uniform medium, fluctuations in the magnetic field direction, departures from spherical expansion

Degeneracy between the strength of the initial field and its orientation relative to the line of sight

For $\theta_0 = 40^\circ$, the strength of the field in the Mon OB2 cloud is $B_0 = 5.0\mu G$

Summary

- ⋆ We have developed an analytical model of the magnetic field in a spherical bubble-shell structure:

  - The change in the initial magnetic field structure is defined by the change in the distribution of matter
  - The model can be used to reproduce radio and sub-mm polarization observations

- ⋆ We have studied the magnetic field structure in the Rosette massive star forming region in the Mon OB2 molecular cloud

  - The model reproduces the mean polarization properties observed by *Planck* towards the dust shell and the radio polarization measured in the HII region

- ⋆ This methodology can be directly applied to other objects to constrain the structure as well as the strength of the magnetic field in massive star forming regions

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

planck

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.