Magnetic fields and massive stellar feedback

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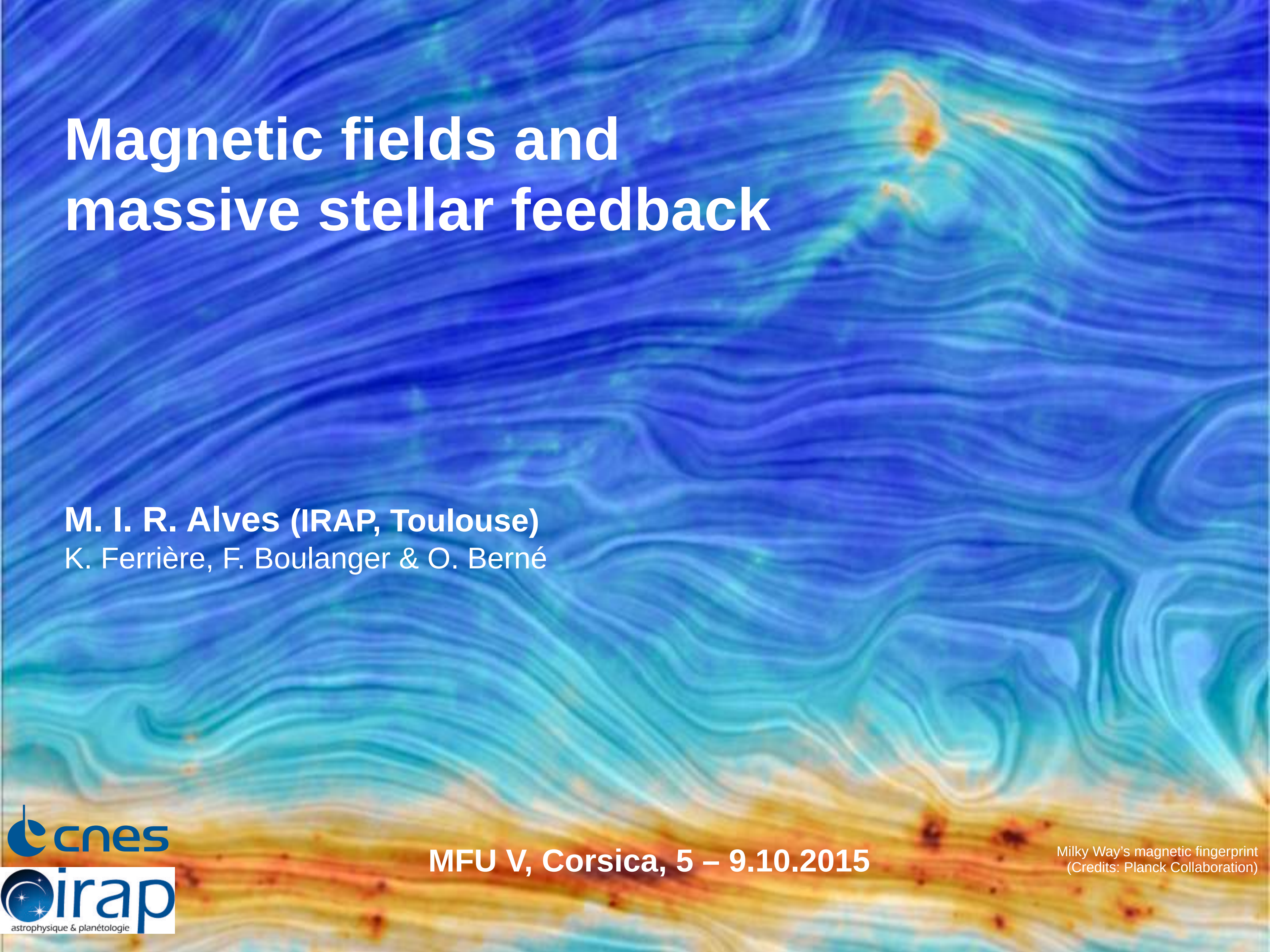


Milky Way's magnetic fingerprint
(Credits: Planck Collaboration)

Outline

- ★ Evolution of massive star-forming regions and its impact on the magnetic field:

  - some examples: strength & orientation of the field
  - **what happens to the magnetic field in photodissociation regions (PDRs)**?

- ★ An analytical solution of the magnetic field in an interstellar bubble (HII region + PDR + molecular cloud)

- ★ Under which conditions do we expect magnetic fields to dominate the dynamical evolution of PDRs?

- ★ The future: study the magnetic field in PDRs with SOFIA, IRAM 30m & ALMA

Massive stellar feedback

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

- ★ Powerful stellar winds
- ★ Starlight momentum
- ★ HII regions
- ★ Supernovae

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

Cygnus X (HOBYS/Herschel – PACS/SPIRE, Motte et al. 2010)

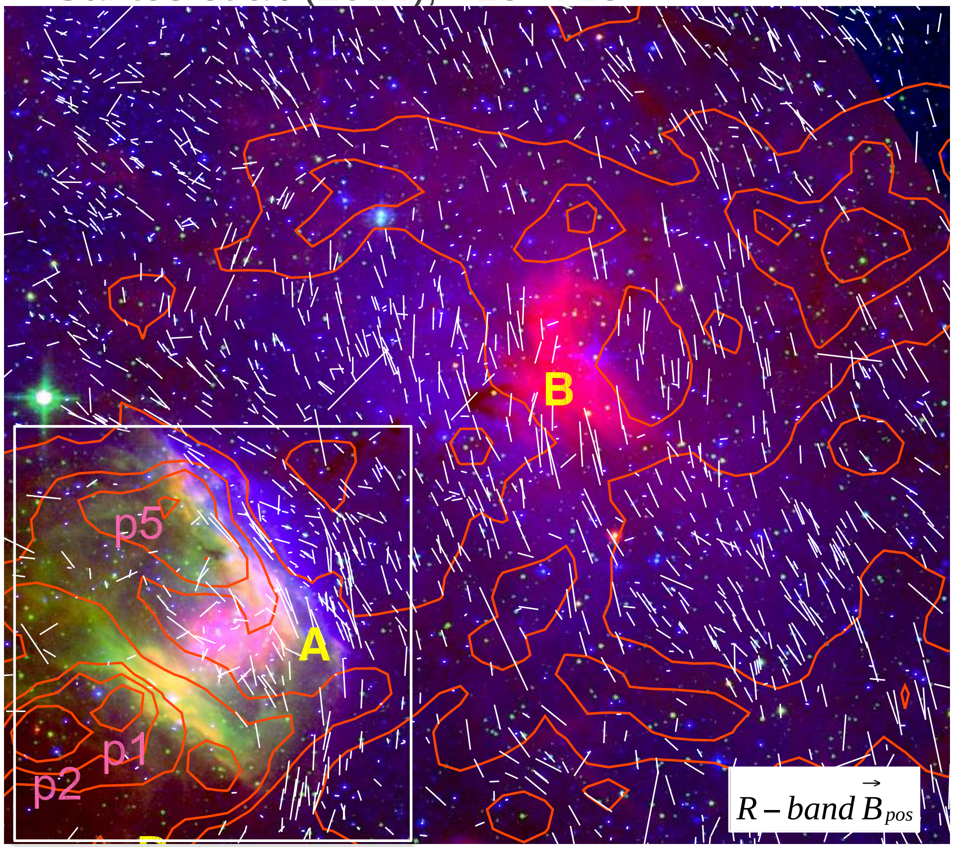
Photodissociation regions (PDRs) are found at the edge of these interstellar bubbles: the interface between the HII region and the molecular clouds, illuminated by the FUV photons from the massive stars.

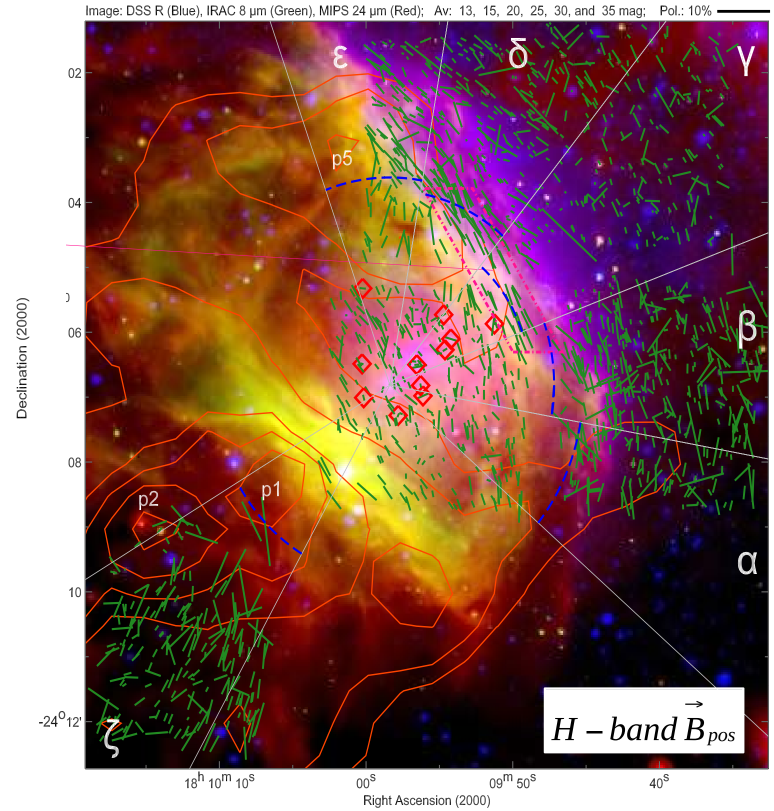
PDRs are usually modelled ignoring gas dynamics (Hollenbach & Tielens 1999):
→ *Is the magnetic field important for the* ***dynamical evolution of PDRs****?*

How is the ***magnetic field*** *affected by massive stellar feedback?*

Magnetic fields in PDRs: Sh2-29 HII region

Santos et al. (2014); ~15' x 15'





$\vec{B}$ lines are **pilled up** at the border of the HII region.

Davis-Chadrasekhar-Fermi method (Davis 1951, C&F 1953):

$$B \propto \frac{\Delta V \sqrt{\rho}}{\delta\theta} \approx 400\mu G$$

→ B ~ 80 times higher than in the diffuse ISM (~ 5 μG, Crutcher 2007)

$G_0 = 150$

$n = 4 \times 10^3 cm^{-3}$

$B = 400 \mu G$

$P_{mag}/k = 5 \times 10^7 cm^{-3} K$

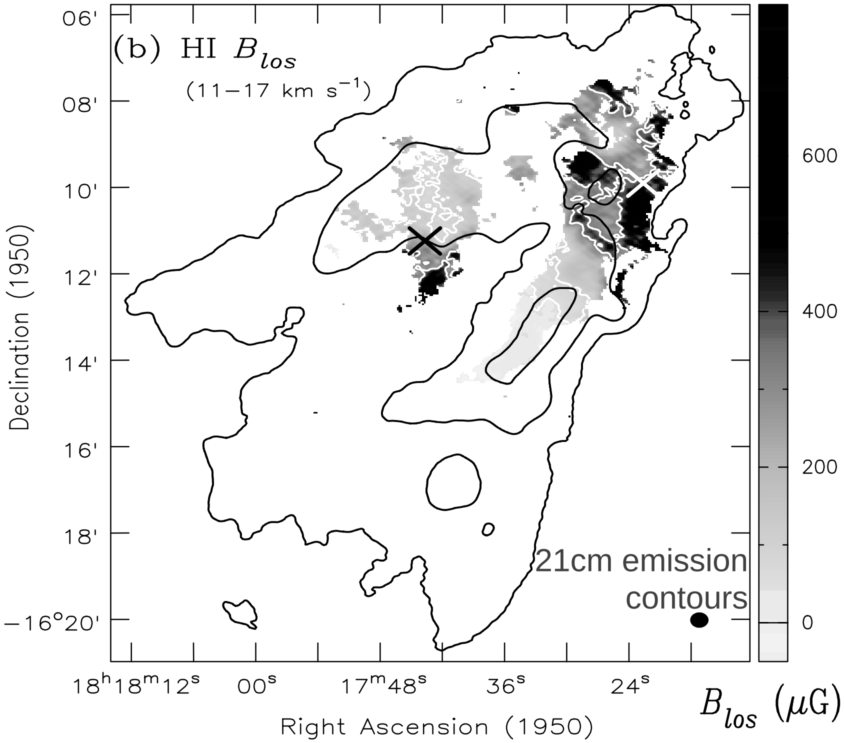
$B_{pos} \leftrightarrow PDR = //$

G_0 – intensity of the incident FUV field (in terms of the average ISRF)

Magnetic fields in PDRs: Omega Nebula M17

Direct measurements of *B* in PDRs via Zeeman effect observations (give $\vec{B}_{line-of-sight}$ only):
e.g. $B_{los,\max} = 750\mu G$ in PDR of M17 (Brogan & Troland 2001)

Spitzer/GLIMPSE (5.8µm red; 4.5µm green; 3.6µm blue)



Magnetic field is dynamically important – it must be taken into account to understand the structure of PDRs (Abel et al. 2004, Pellegrini et al. 2007, 2009)

$G_0 = 8 \times 10^4$

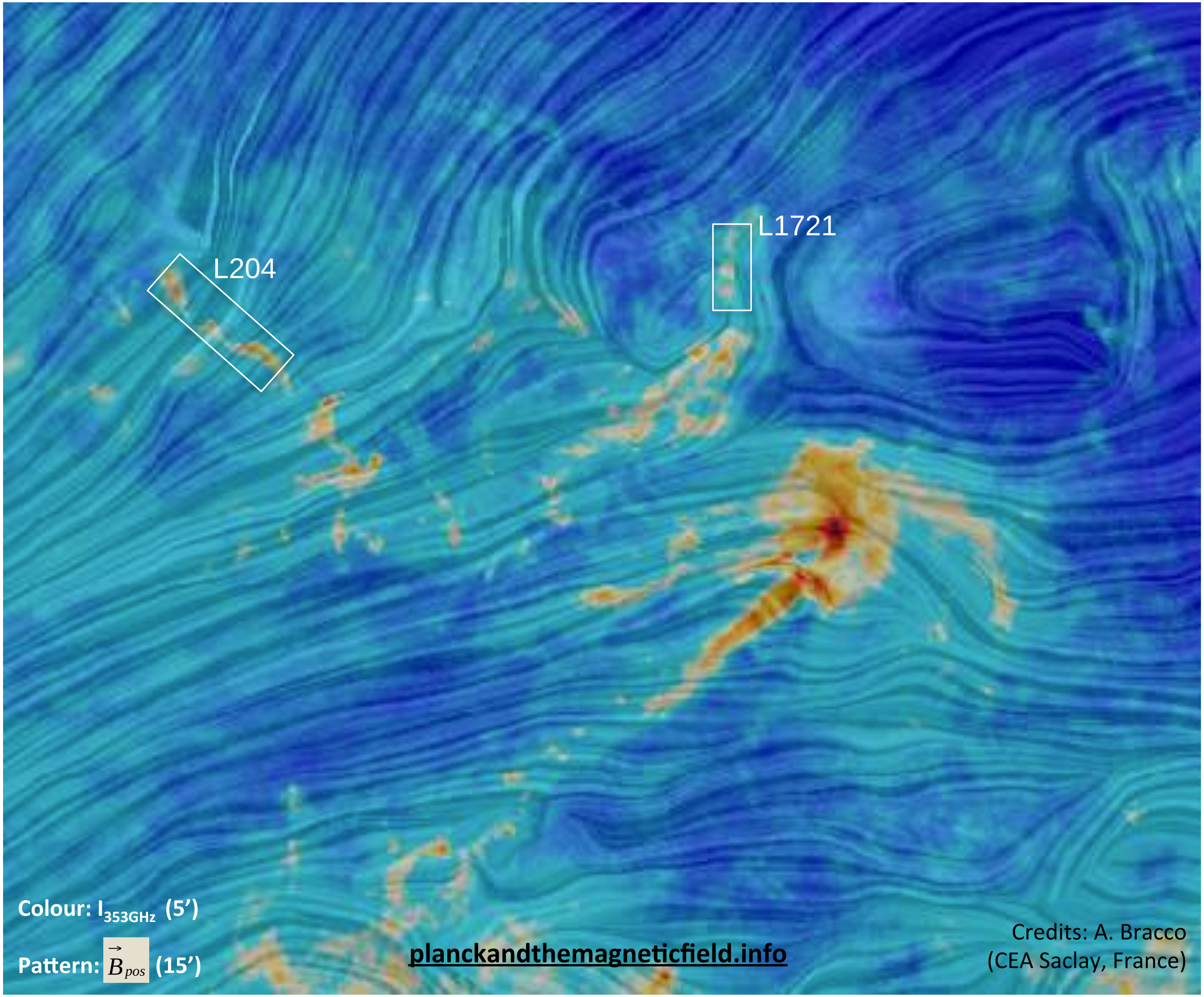
$n = 1 \times 10^4 cm^{-3}$

$B = 50 - 750\mu G$

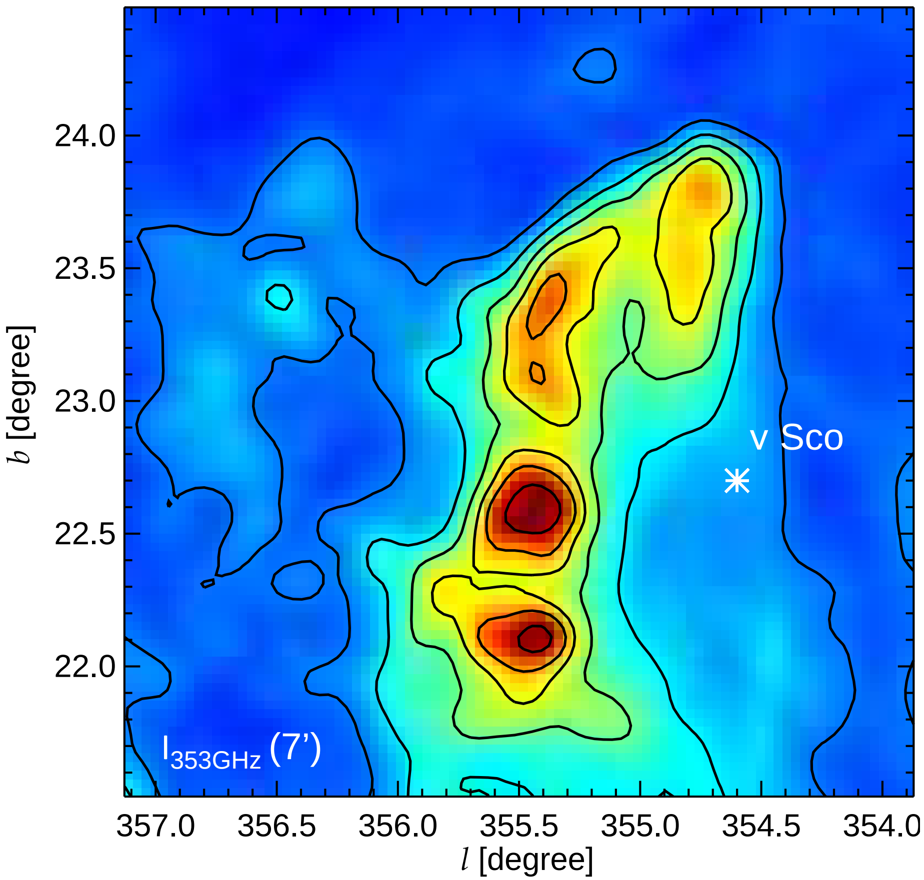
$P_{mag} / k = (1-160) \times 10^6 cm^{-3} K$

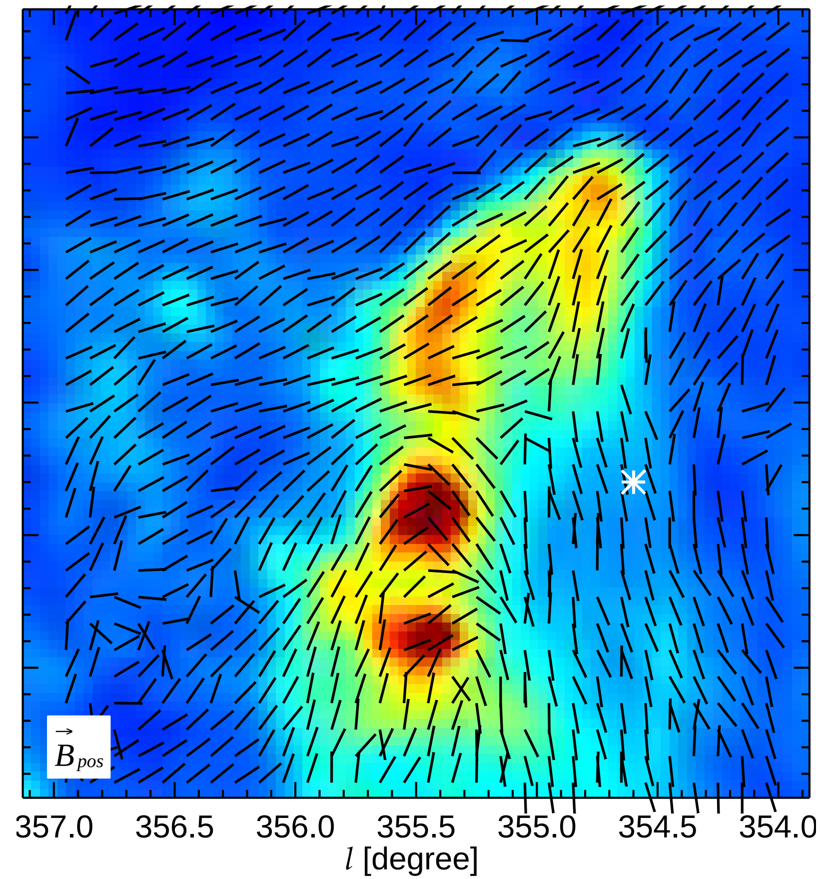
$B_{pos} \leftrightarrow PDR = ?$

The Ophiuchi region as seen by *Planck*



Magnetic fields in PDRs: L1721





$\vec{B}_{pos}$ from *Planck* sub-mm observations of dust polarized emission.

No effect from the star on $\vec{B}$.

$G_0 = 8$

$n = 3\times10^3 cm^{-3}$

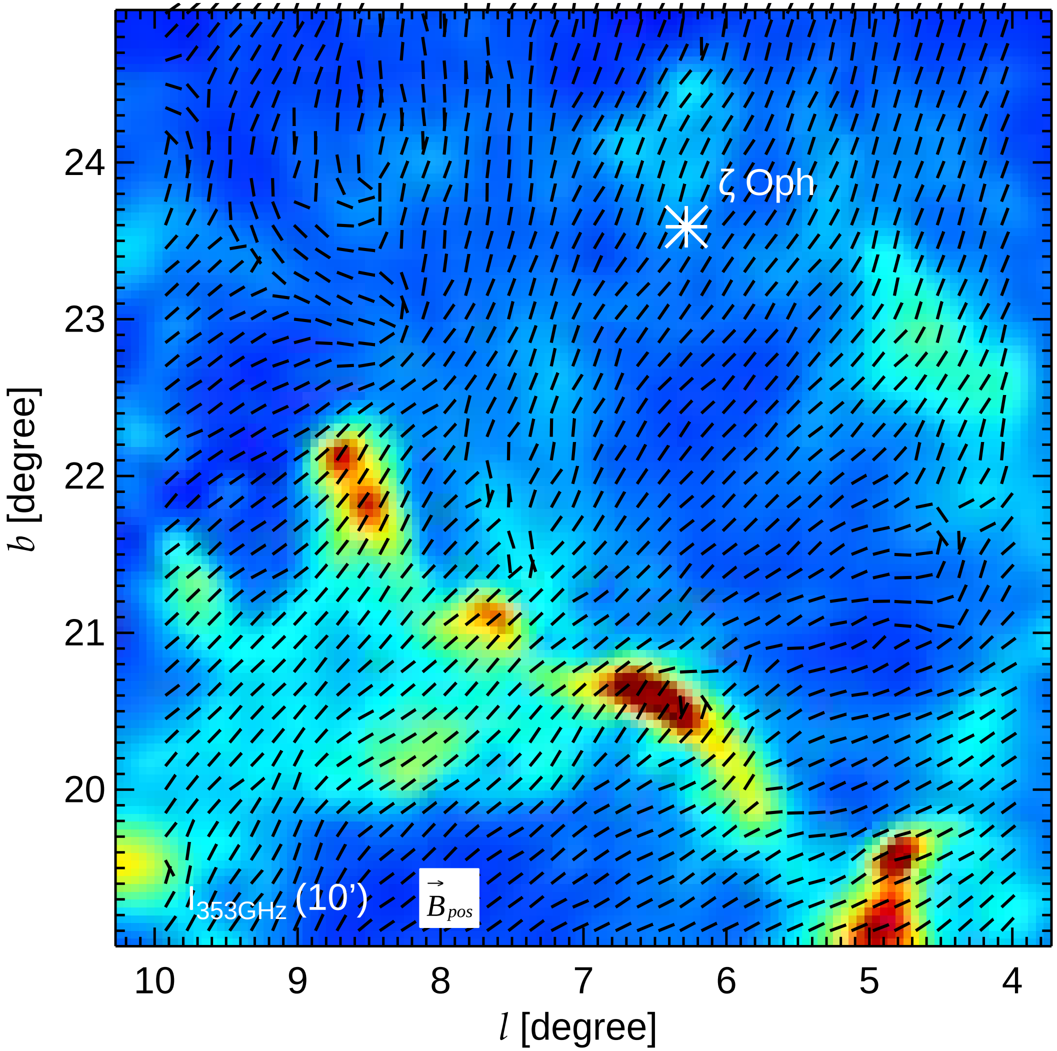
$B = ?$

$P_{mag} / k = ?$

$B_{pos} \leftrightarrow PDR = \perp$

Habart et al. (2001)

Magnetic fields in PDRs: L204



Zeeman effect observations (Heiles 1988):

$$B_{los,\max} = 9\mu G$$

$\vec{B}_{pos}$ studies (near-IR and optical polarization of dust extinction): McCutcheon et al. (1986), Cashman & Clemens (2014)

$G_0 = 30$

$n = 1\times10^3 cm^{-3}$

$B = 12\mu G$

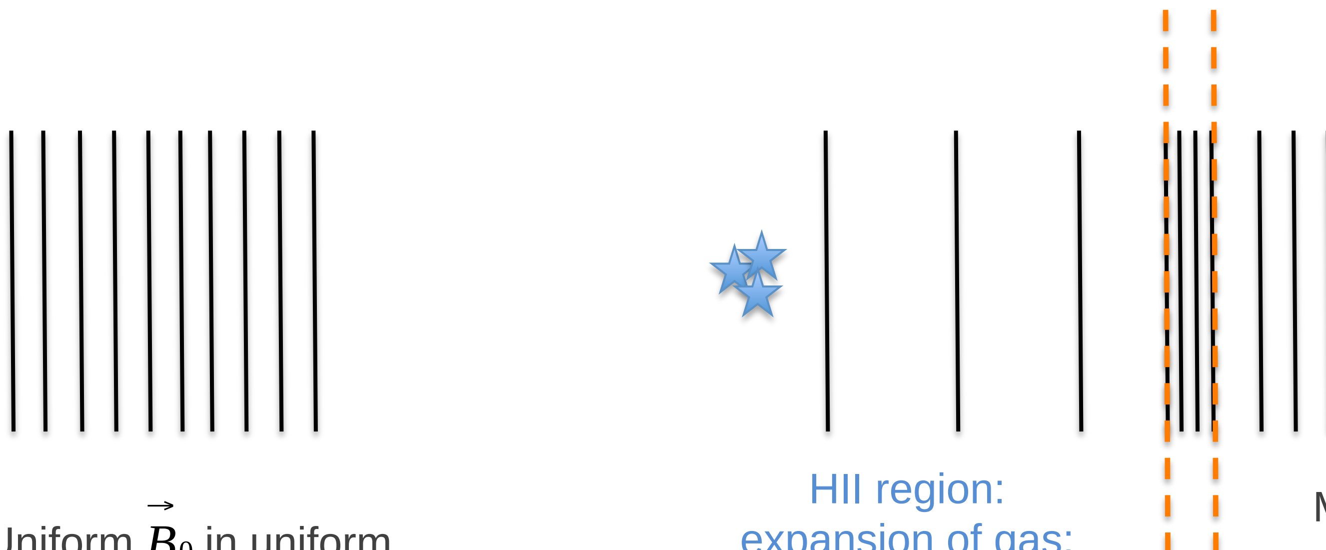
$P_{mag} / k = 4\times10^4 cm^{-3} K$

$B_{pos} \leftrightarrow PDR = \perp$

Magnetic fields in massive star-forming regions

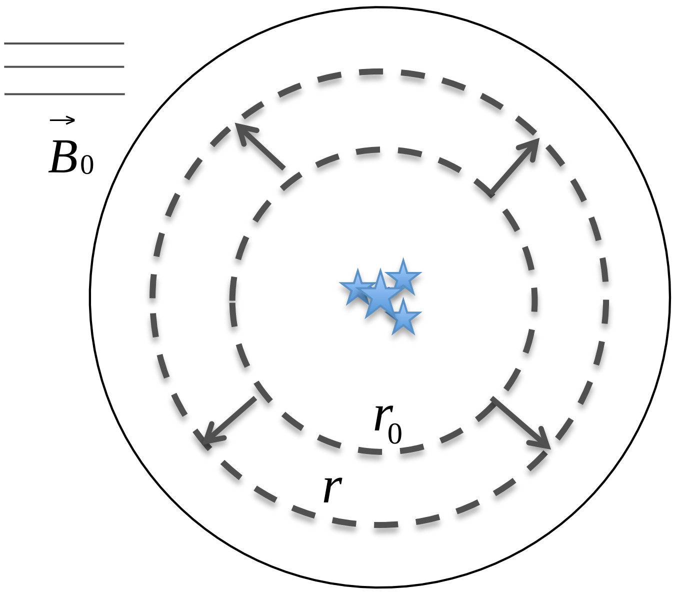
How is the **magnetic field** affected by **massive stellar feedback**?

→ Field lines are dragged with the gas (frozen-in condition)



Analytical model: the magnetized Strömgren shell

Planck intermediate results. XXXIV. (2015): The magnetic field structure in the Rosette Nebula

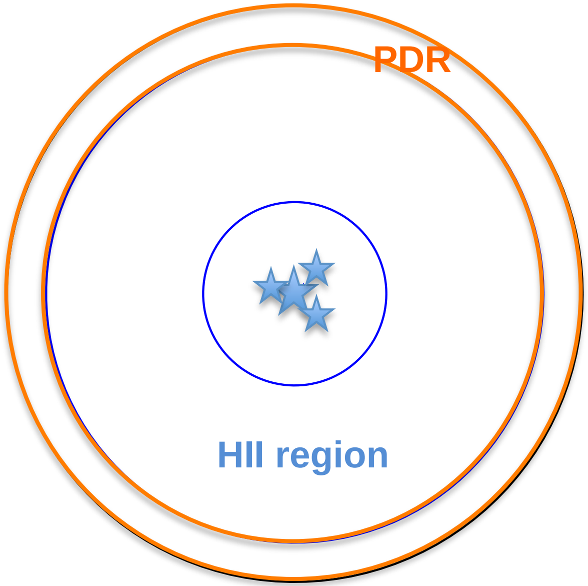


- Radial expansion of the gas:
  - uniform and spherical structure
  - using conservation of mass

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

- Frozen-in condition:
  - start from a uniform $\vec{B}_0$
  - field lines follow the gas $\boldsymbol{A}(\boldsymbol{r}) = (\nabla \boldsymbol{r}_0) \cdot \boldsymbol{A}_0(\boldsymbol{r}_0)$
    (Parker 1970)

$$\vec{B}(\vec{r}) = \left(\frac{r_0}{r}\right)^2 B_{0r}\,\vec{e}_r + \frac{r_0}{r}\frac{dr_0}{dr}\left(B_{0\theta}\,\vec{e}_\theta + B_{0\phi}\,\vec{e}_\phi\right)$$



(Previous analytical and numerical studies: e.g. Ferrière et al. 1991, Krumholz et al. 2007, Arthur et al. 2011)

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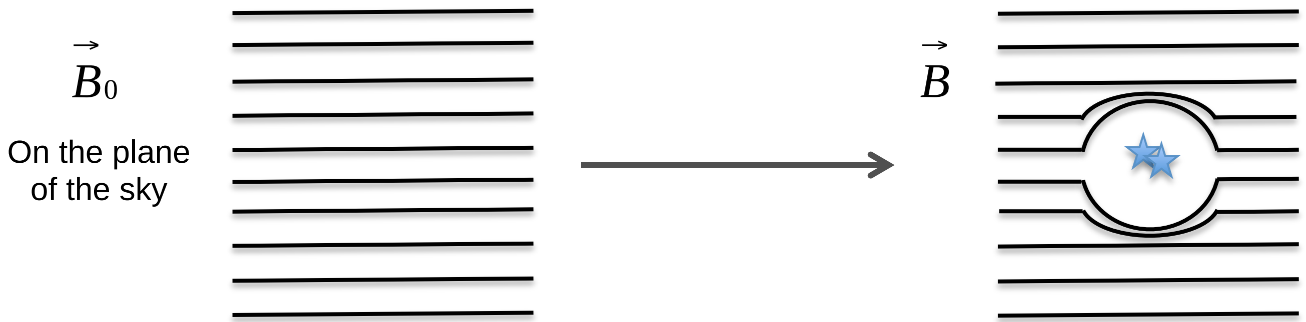
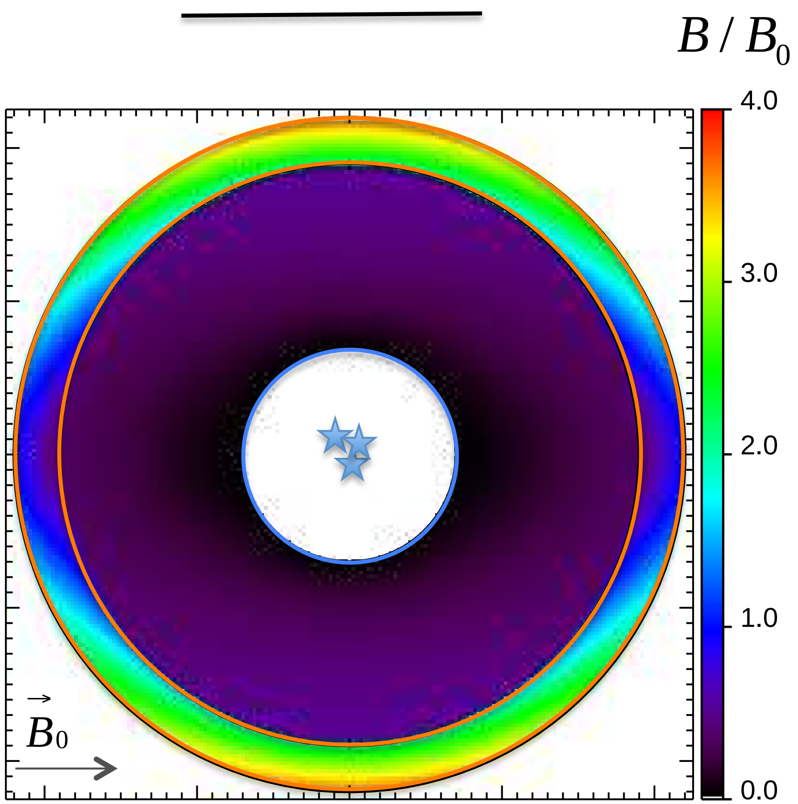




The field is most compressed perpendicular to $\vec{B}_0$.

Along $\vec{B}_0$, $B = B_0$ at the outer surface and B decreases inwards.

Note: Exact B / B_0 ratios depend on $r_{final} = f(r_{initial})$ - the way that matter has expanded – this particular example applies to the Rosette Nebula.

Magnetic fields in PDRs

Under which conditions does the **magnetic field dominate in the PDR**? (ignoring turbulent pressure)

$$P_{th}^{HII} + P_{rad} = P_{th} + P_{mag} \Leftrightarrow n_e T_e + \frac{L}{4\pi d^2 c} = nT + \frac{B^2}{8\pi}$$

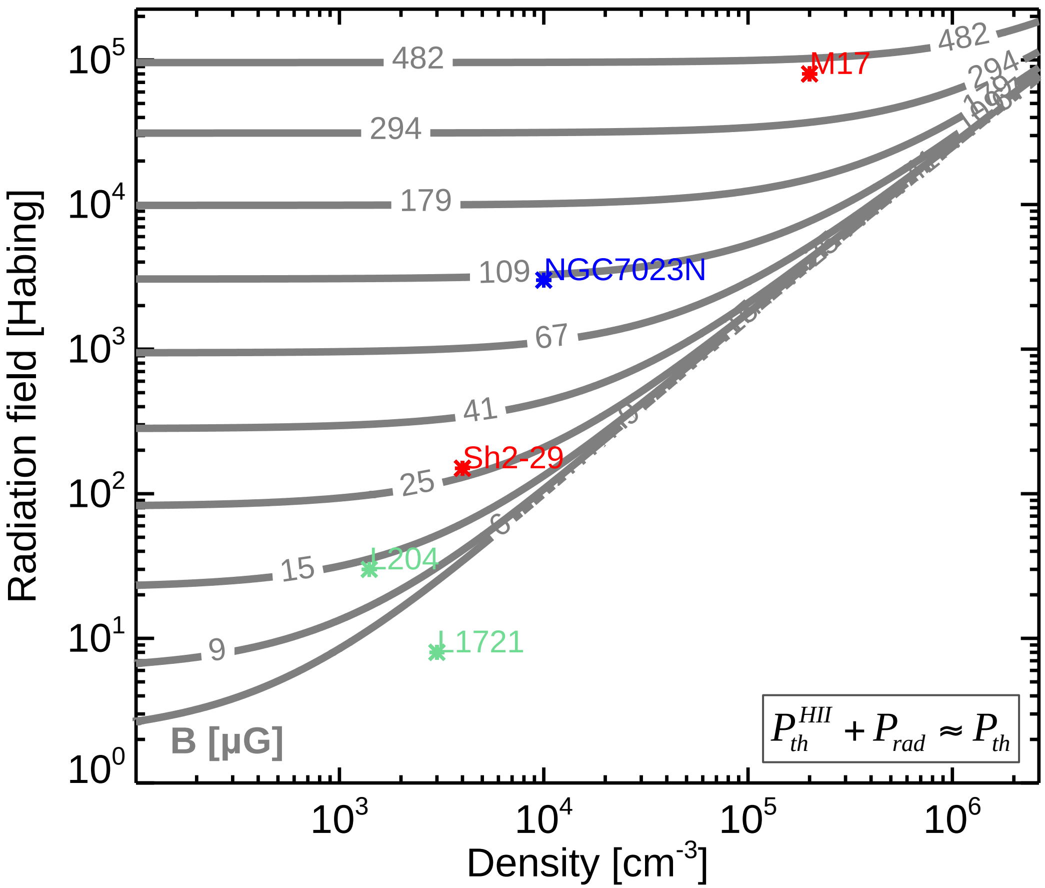
$$B = \frac{100}{\sqrt{2.9\times 10^6}}\left(n_e T_e + 376 G_0 - nT\right)^{1/2}$$

with $G_0 = \frac{L_{FUV}}{4\pi d^2}$,

$T = 20K, T_e = 7000K$

and n_e given by the Strömgren solution (density-size relation).

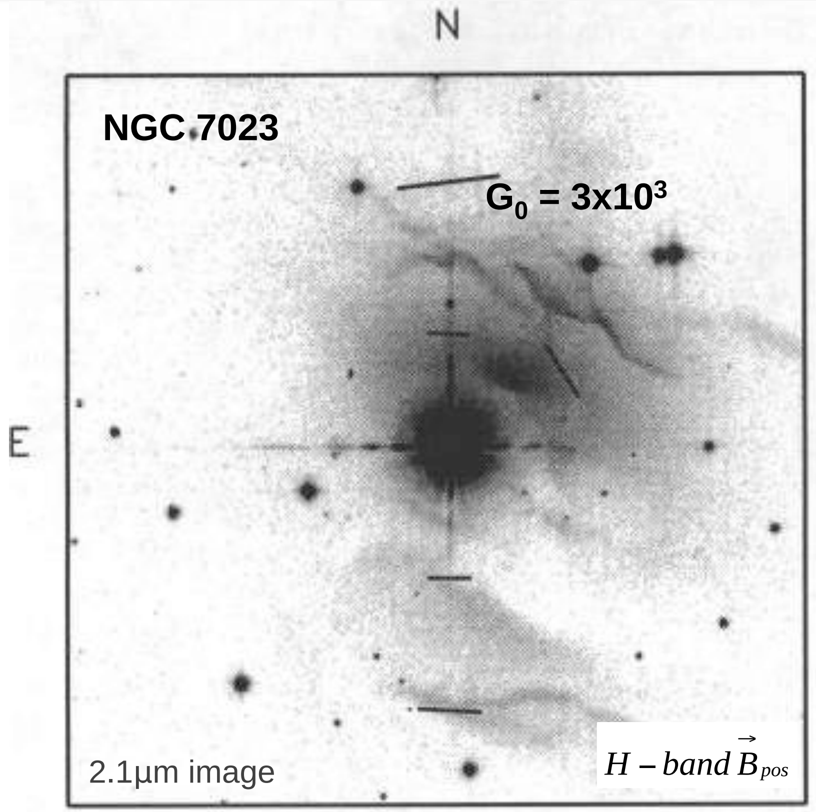
Simple diagnostic to test with observations → relative orientation between PDR and $\vec{B}$



(G_0, n): Habart et al. (2011), Pilleri et al. (2012), Pellegrini et al. (2007, 2009)

Future observations

Looking for the signatures of magnetic field compression…



Sellgren et al. (1992); 3.'2 x 3.'2

Summary

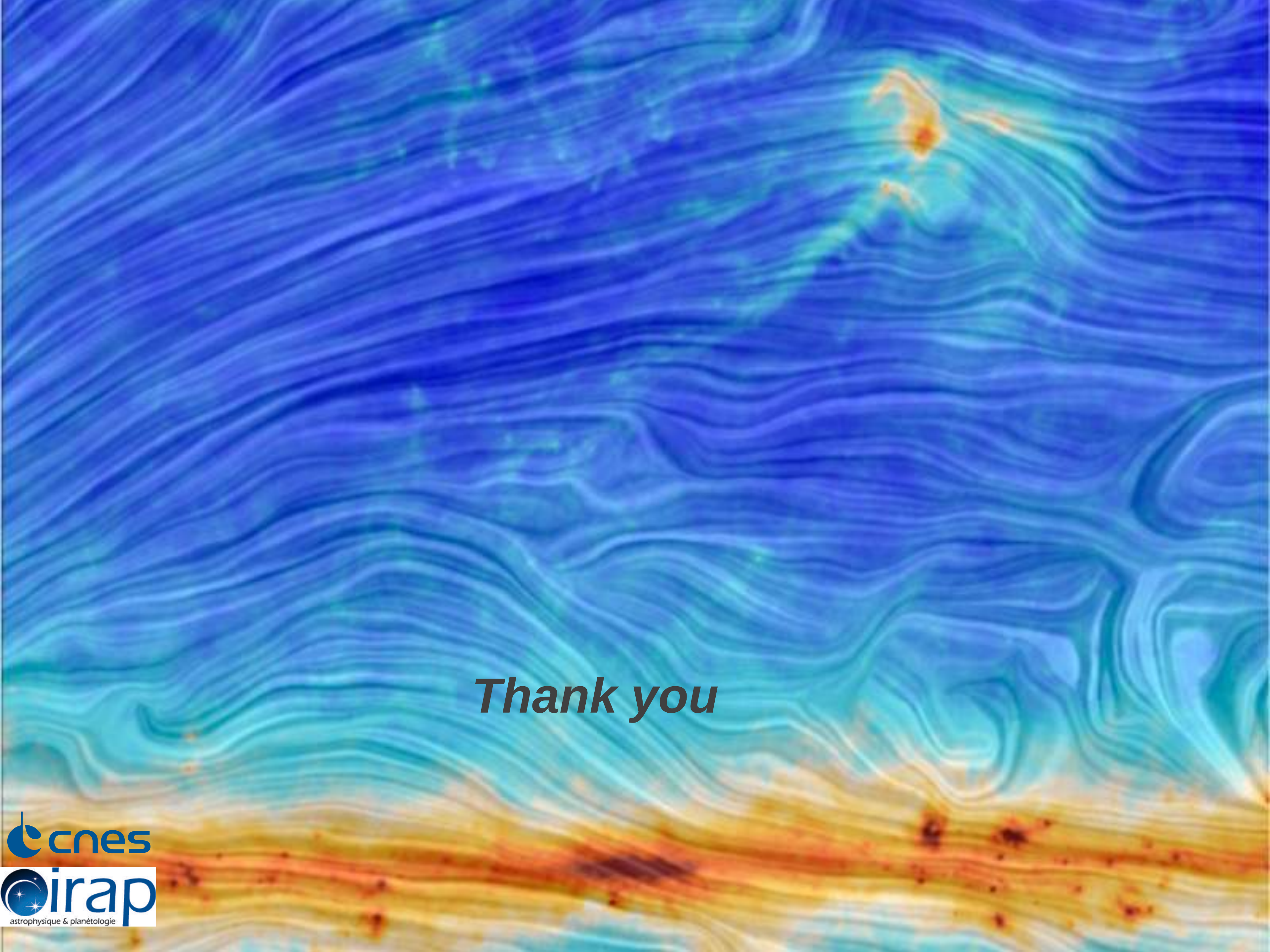
- ★ Depending on the physical conditions (G_0,n):

  → magnetic fields are dragged by the expansion of matter in massive star forming regions (by radiation pressure + ionized gas pressure)

  → field lines are compressed in PDRs

  → magnetic pressure increases and may become comparable to the gas pressure

  Magnetic fields should be taken into account in the dynamical evolution of PDRs, as they may influence their structure.



Thank you