The Link between Magnetic Fields and Cloud/ Star Formation

MVSem: Star Formation

Henrik Ruh

Supervisor: Prof. Dr. Henrik Beuther

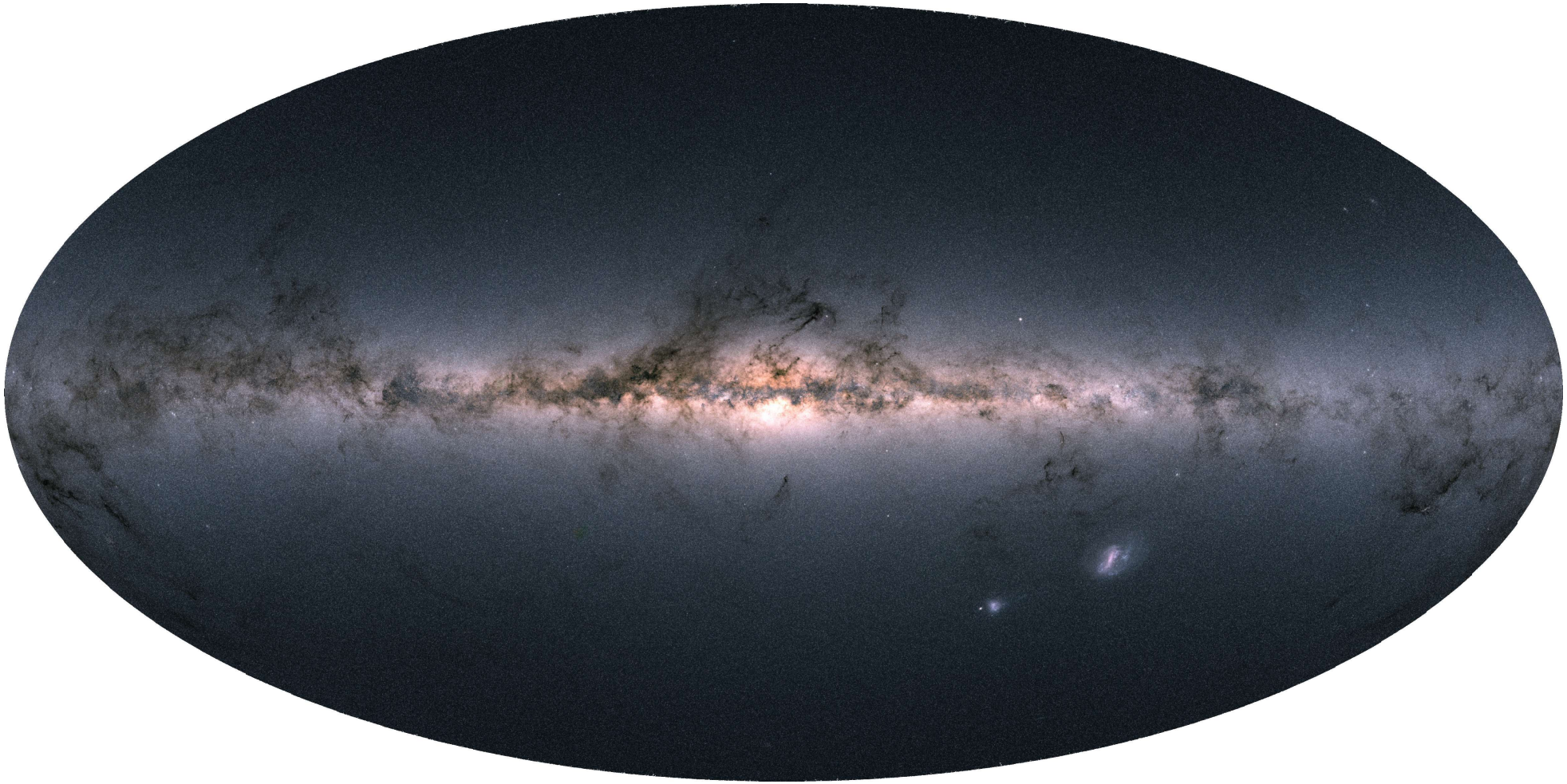
November 22, 2018

Take Away

- magnetic fields are important
- magnetic fields channel self-gravity and turbulence
- magnetic fields interconnect large scales with small scales

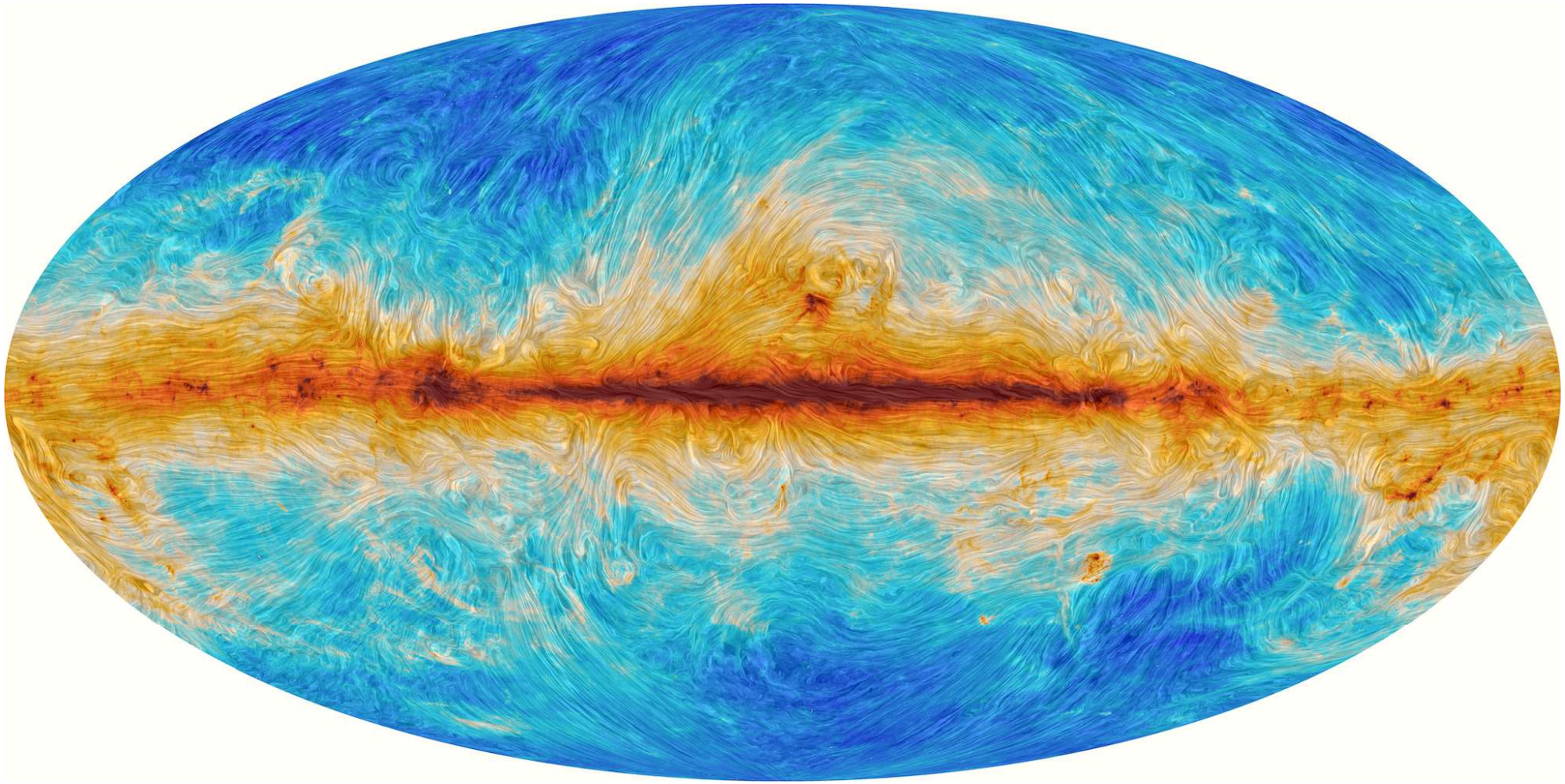
Outline

A Sky Full of Stars



(Credit: ESA/Gaia/DPAC)

Galactic B-field



(Planck Collaboration Int. XXXV 2016)

Can We Simulate Star Formation?

(Krumholz, Klein, and McKee 2012)

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- observations: $\dot{M}_\star \approx 1.3\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$

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Simulation Outcomes

run with	ϵ_{ff}
turbulence	0.33
turbulence and protostellar outflows	0.28

(Krumholz, Klein, and McKee 2012)

Why Are Magnetic Fields Important?

Flux-freezing

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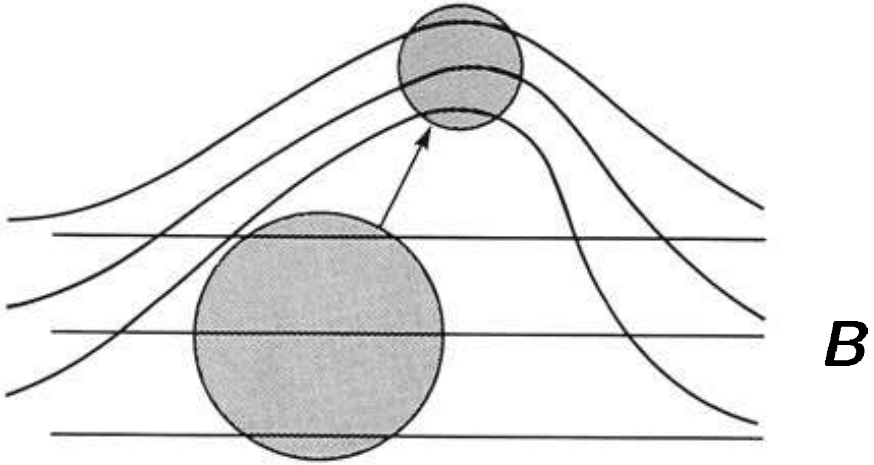

(Shu 1982)

Why Are Magnetic Fields Important?

Lorentz force

$$\boldsymbol{f}_{\mathrm{L}} = \frac{1}{4\pi} \left(\boldsymbol{B} \cdot \nabla \right) \boldsymbol{B} - \frac{1}{8\pi} \nabla \left(|\boldsymbol{B}|^2 \right)$$

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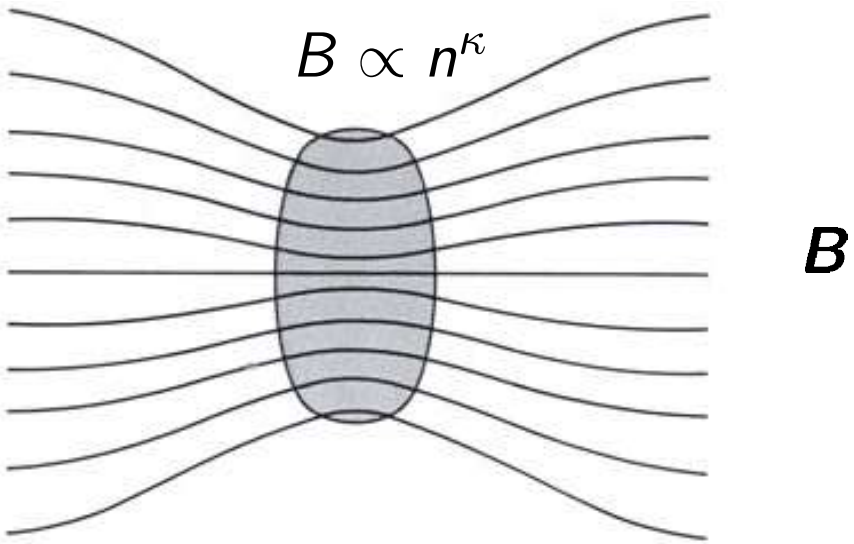

(Shu 1982)

How Do Magnetic Fields Affect Star Formation?

Jeans mass

Virial theorem: $K = -2U \Rightarrow M_{\mathrm{Jeans}} \propto T^{3/2}\rho^{-1/2}$

if $M > M_{\mathrm{Jeans}} \longrightarrow$ cloud collapses to form stars

Magnetically critical mass

Virial theorem with magnetic energy $\Rightarrow M_\Phi = \Phi/2\pi\sqrt{G}$

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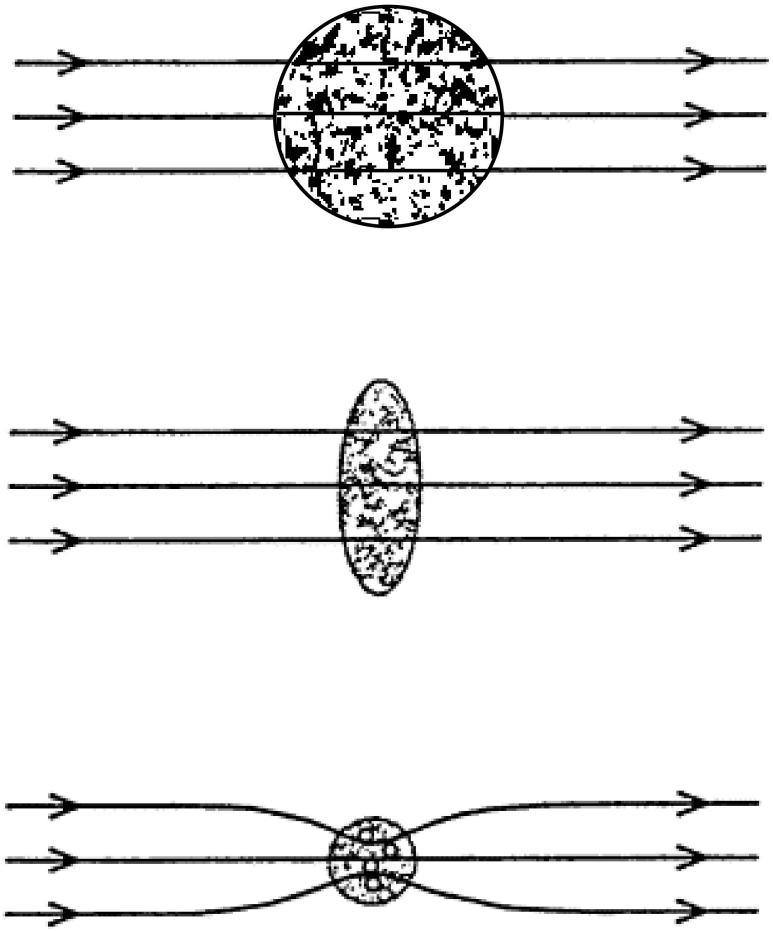
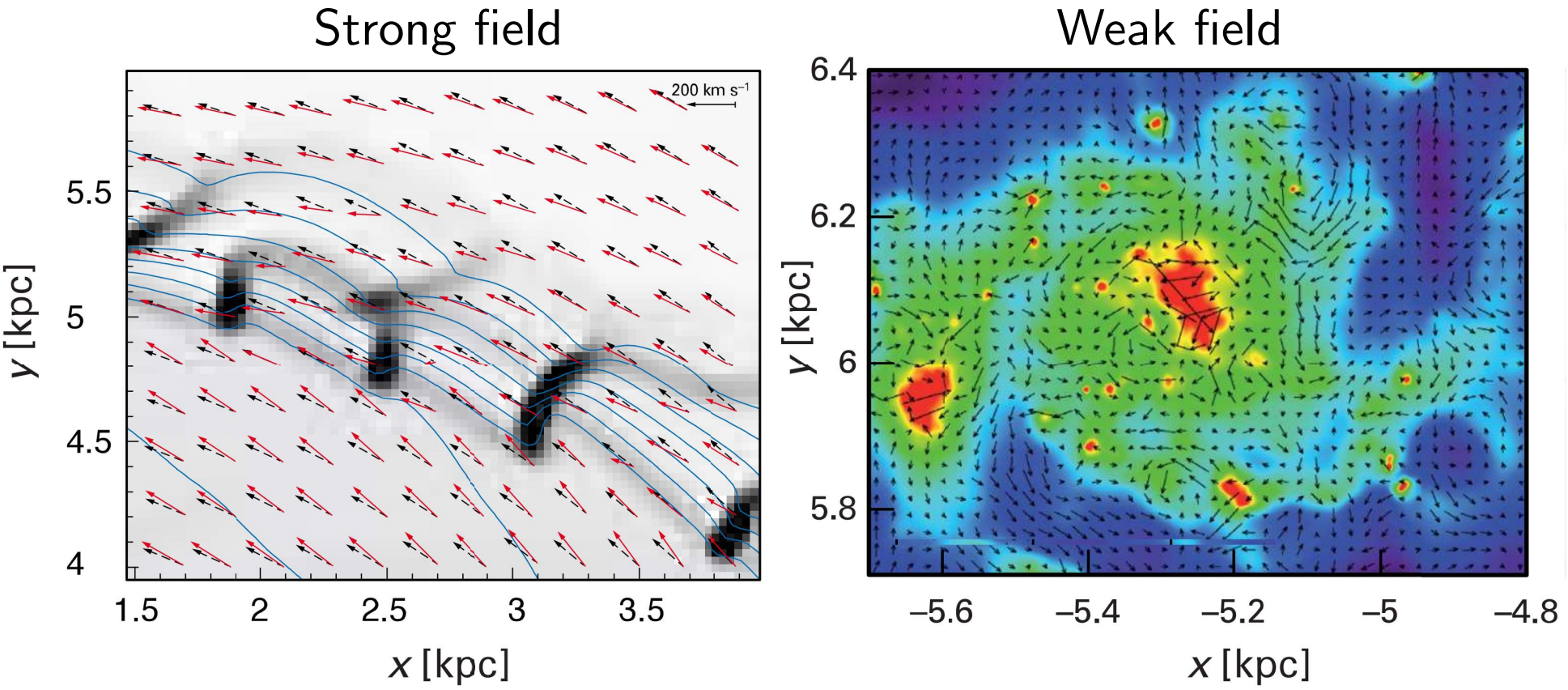


(Vallée 2003)

Observations

Molecular Cloud Formation

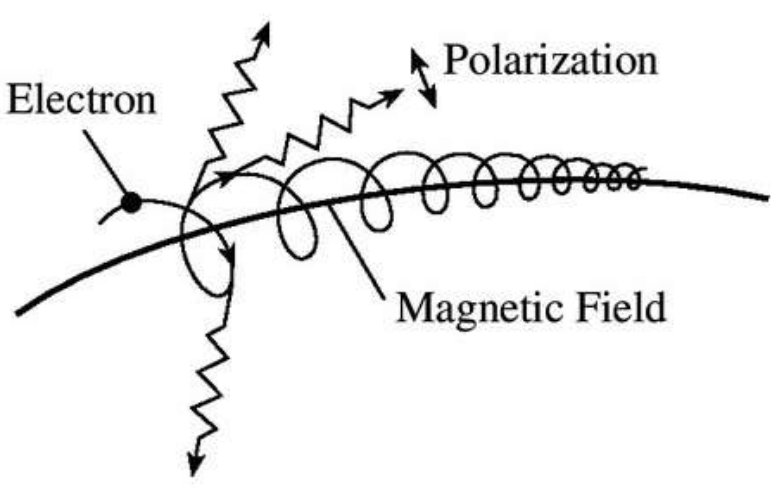
- strong field: contraction along field lines
- weak field: randomisation by turbulence



(Li, Goodman, et al. 2014)

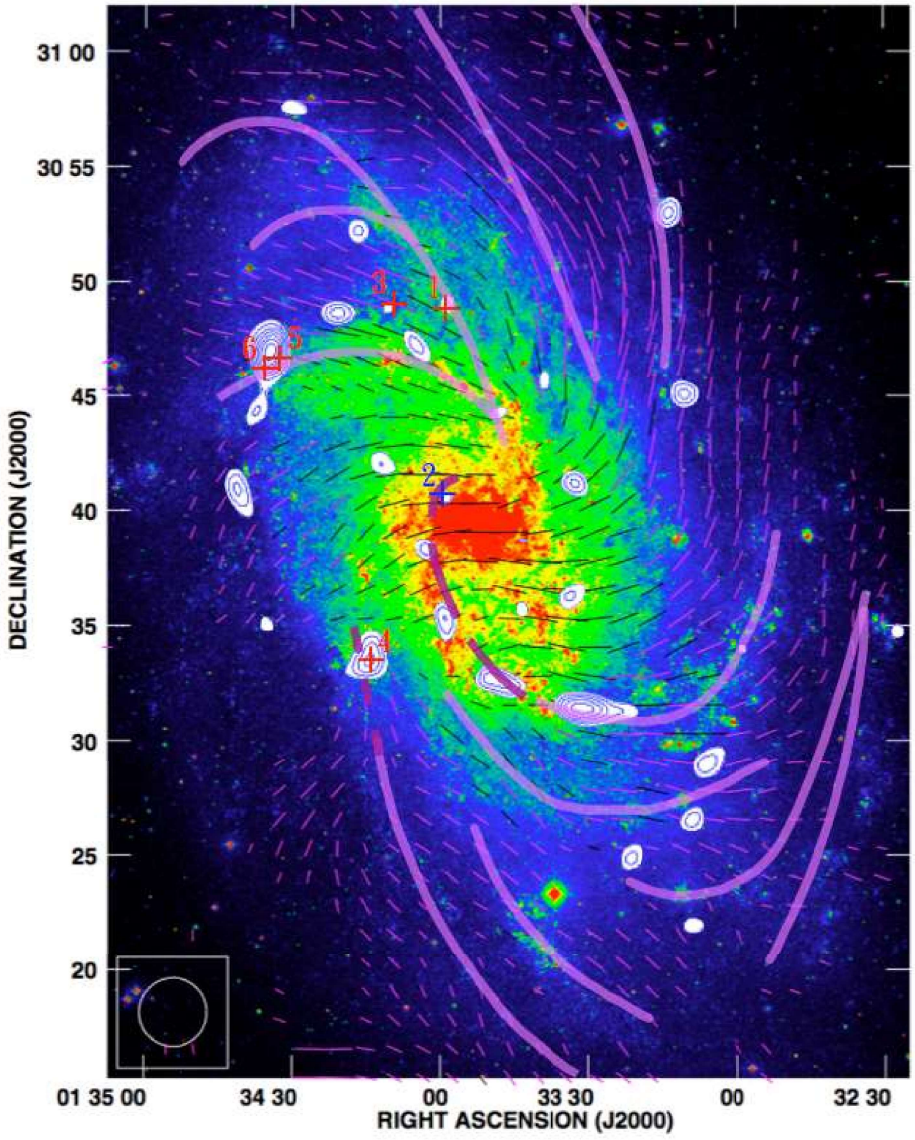
Synchrotron Radiation

- relativistic electron in B-field
- Lorentz force leads to acceleration
- emission polarised perpendicular to $\boldsymbol{B}$



(Lang 2013)

Giant Molecular Clouds in M33



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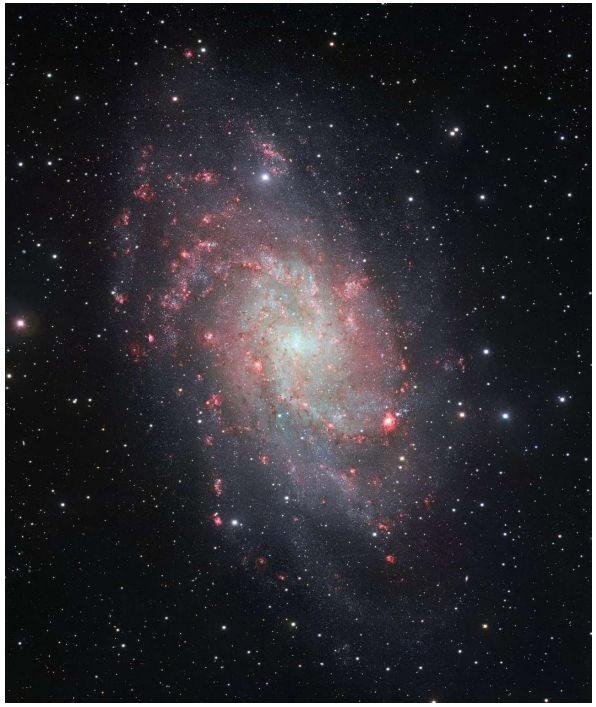

(Credit: ESO)

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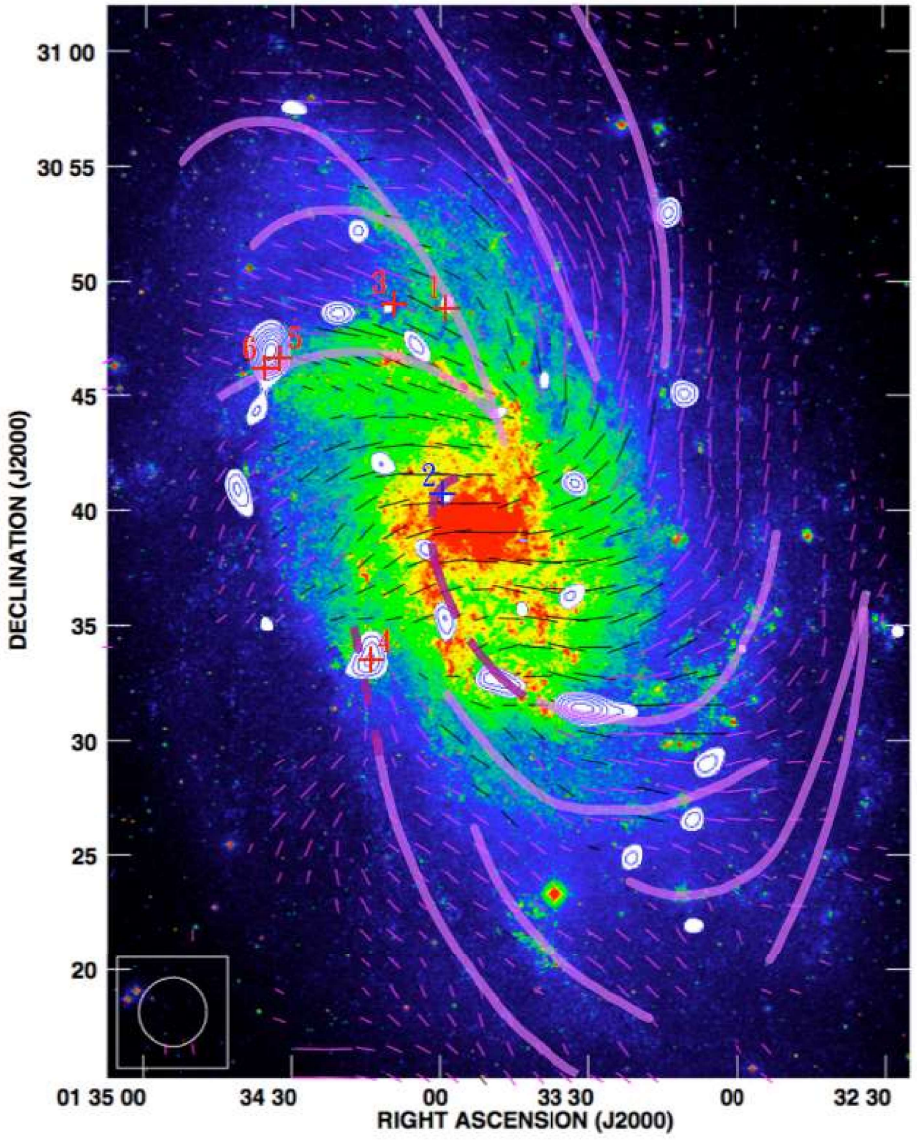

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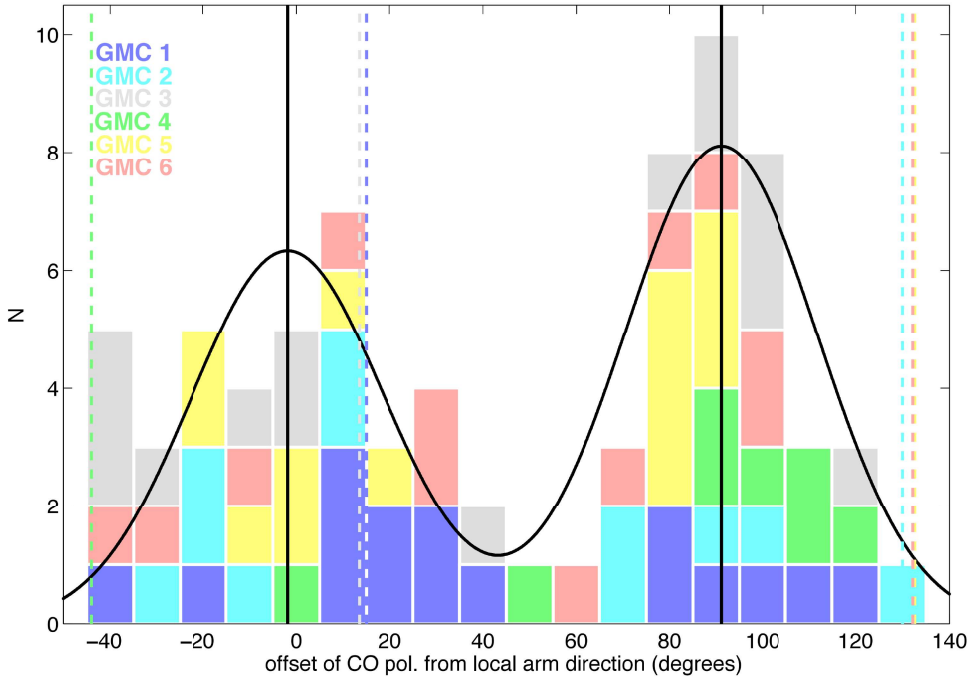

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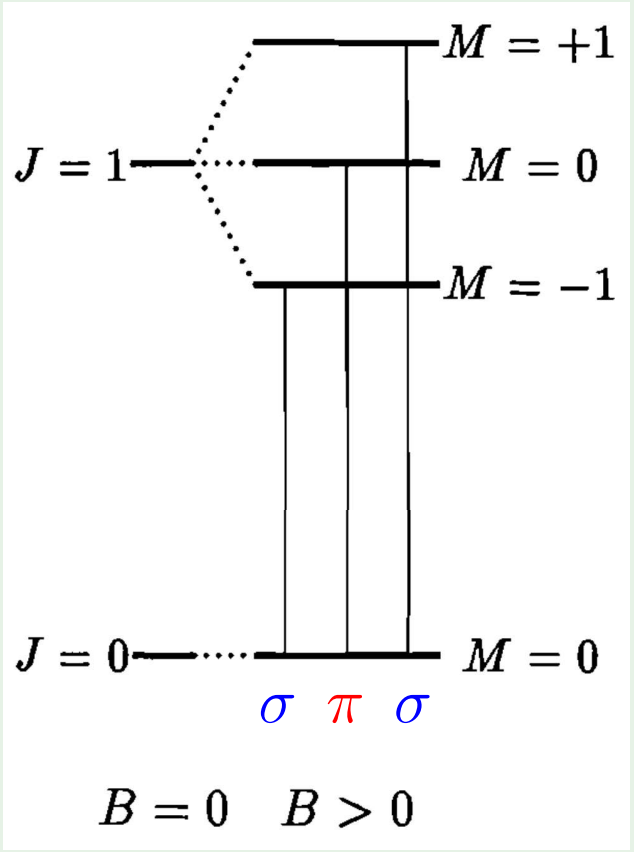
Zeeman Splitting

- frequency shift $\Delta\nu_Z = \pm Z\,|\boldsymbol{B}|$
- π and σ modes are polarised



(DeSerio 2009)

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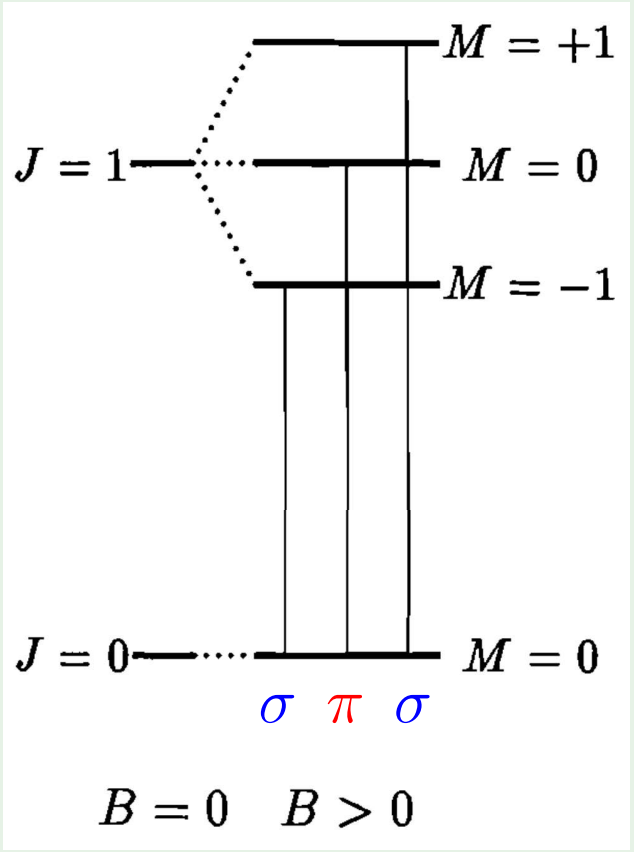

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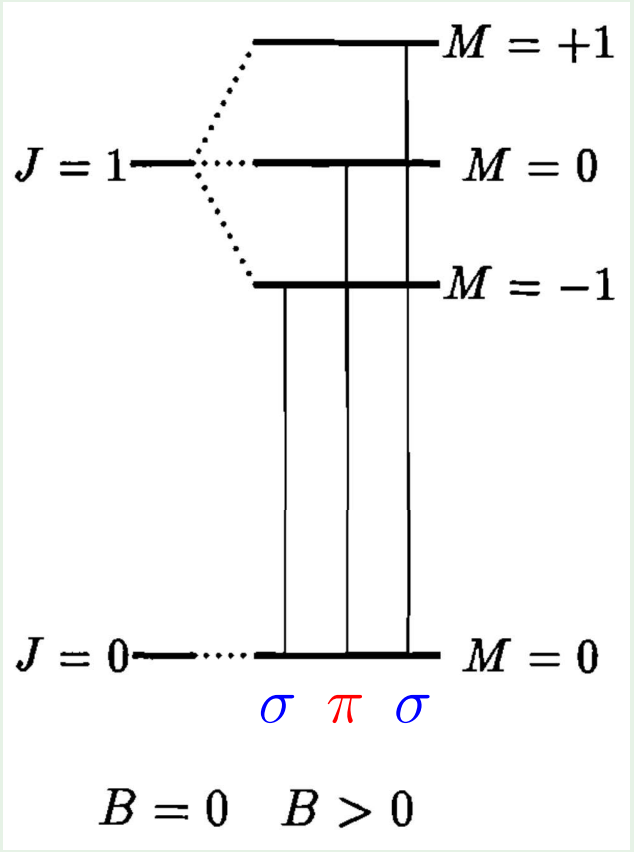

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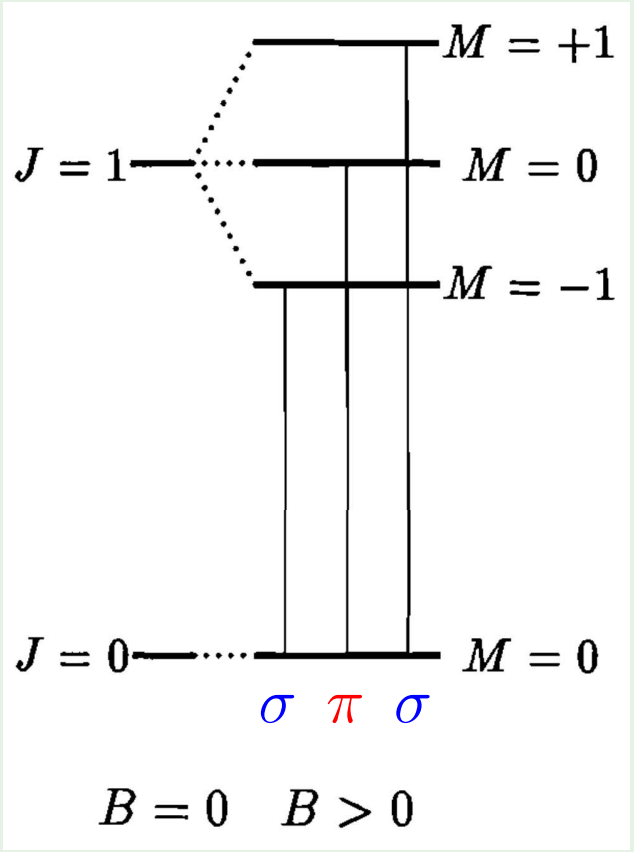

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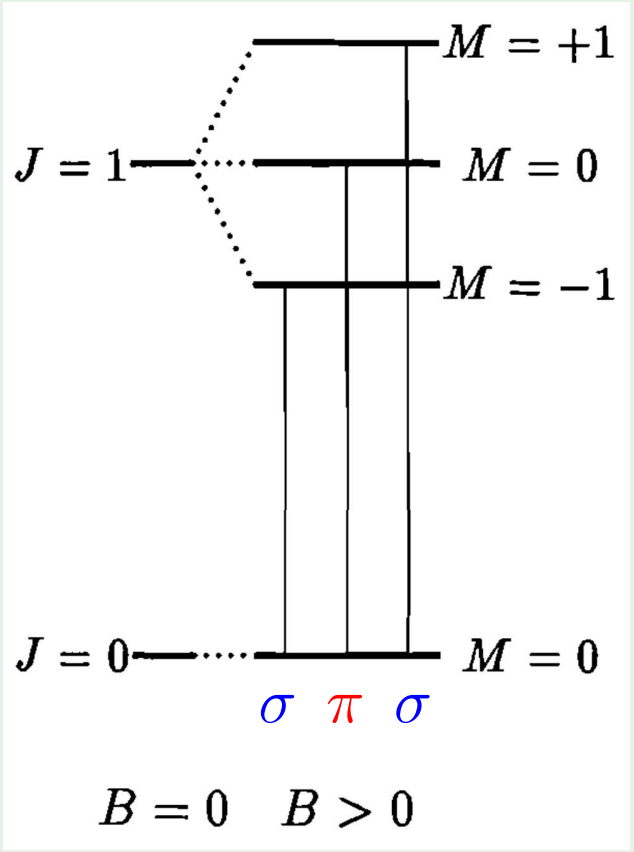
- typically HI, OH, CN lines



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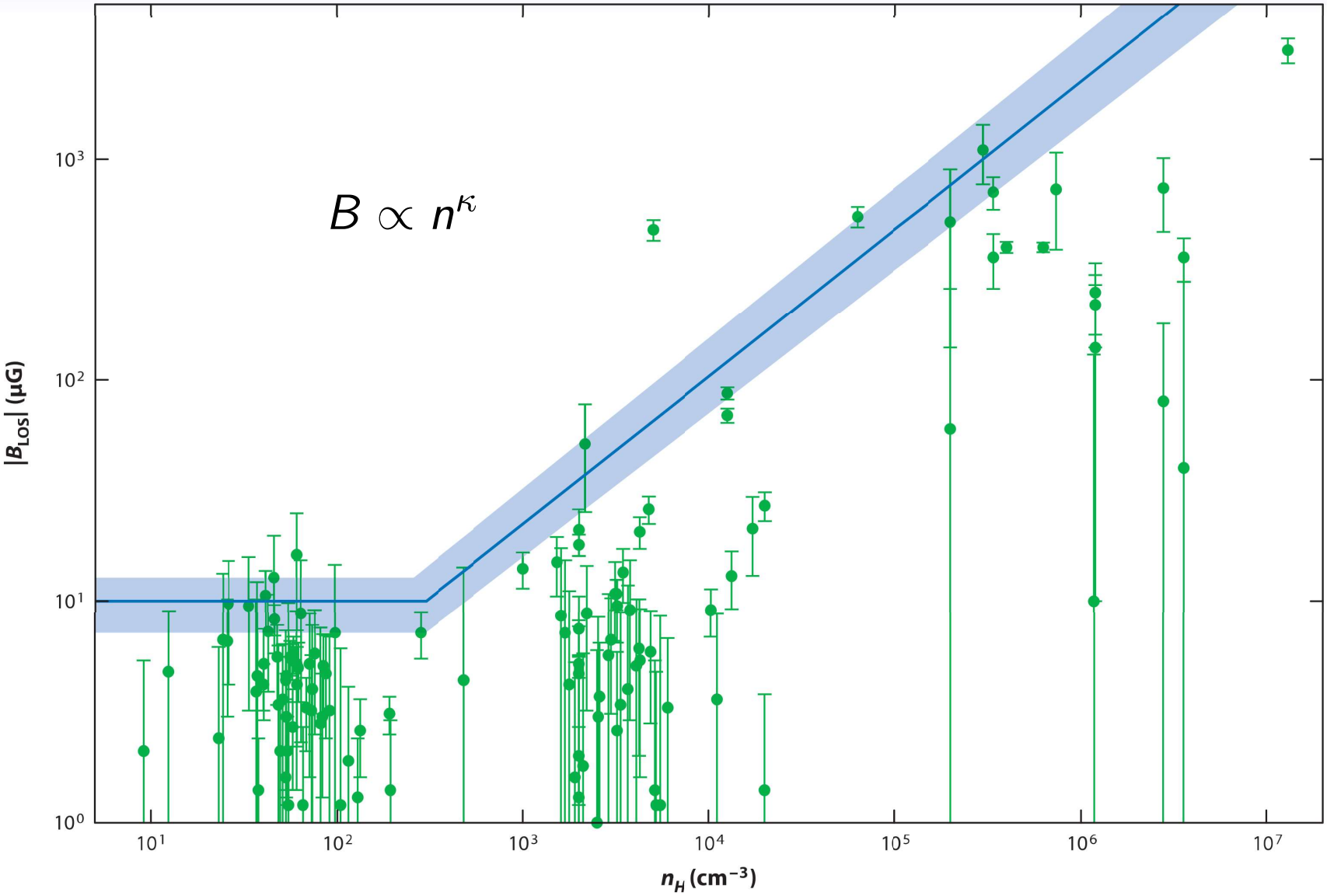
Magnetic Field Strength - Density Relation



(Crutcher 2012)

Filament Formation

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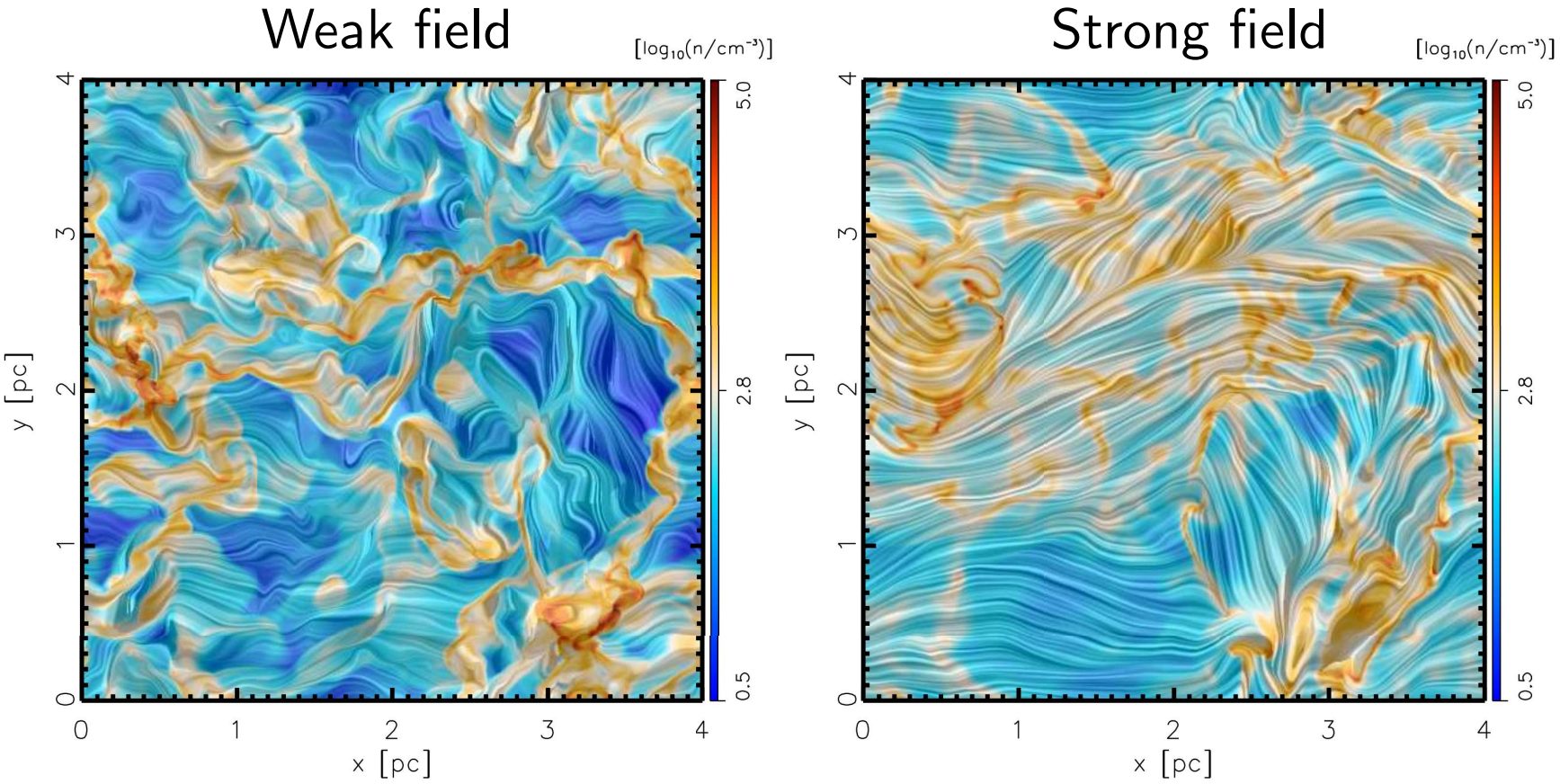
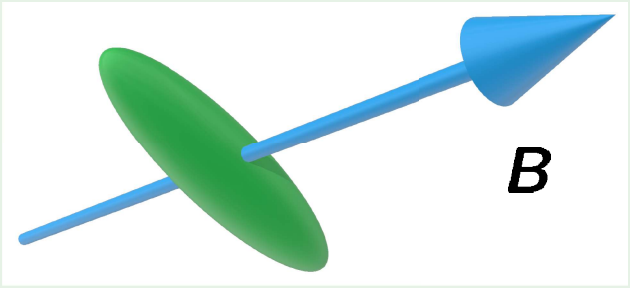


(Soler and Hennebelle 2017)

Polarised Thermal Dust Emission

- grain alignment perpendicular to $\boldsymbol{B}$
- **thermal emission** along long axis



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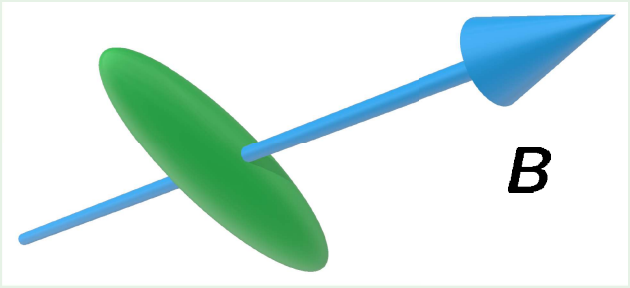

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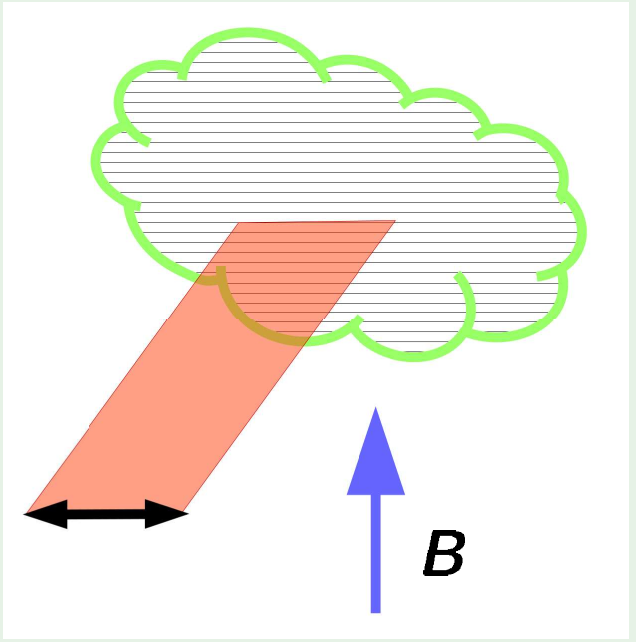
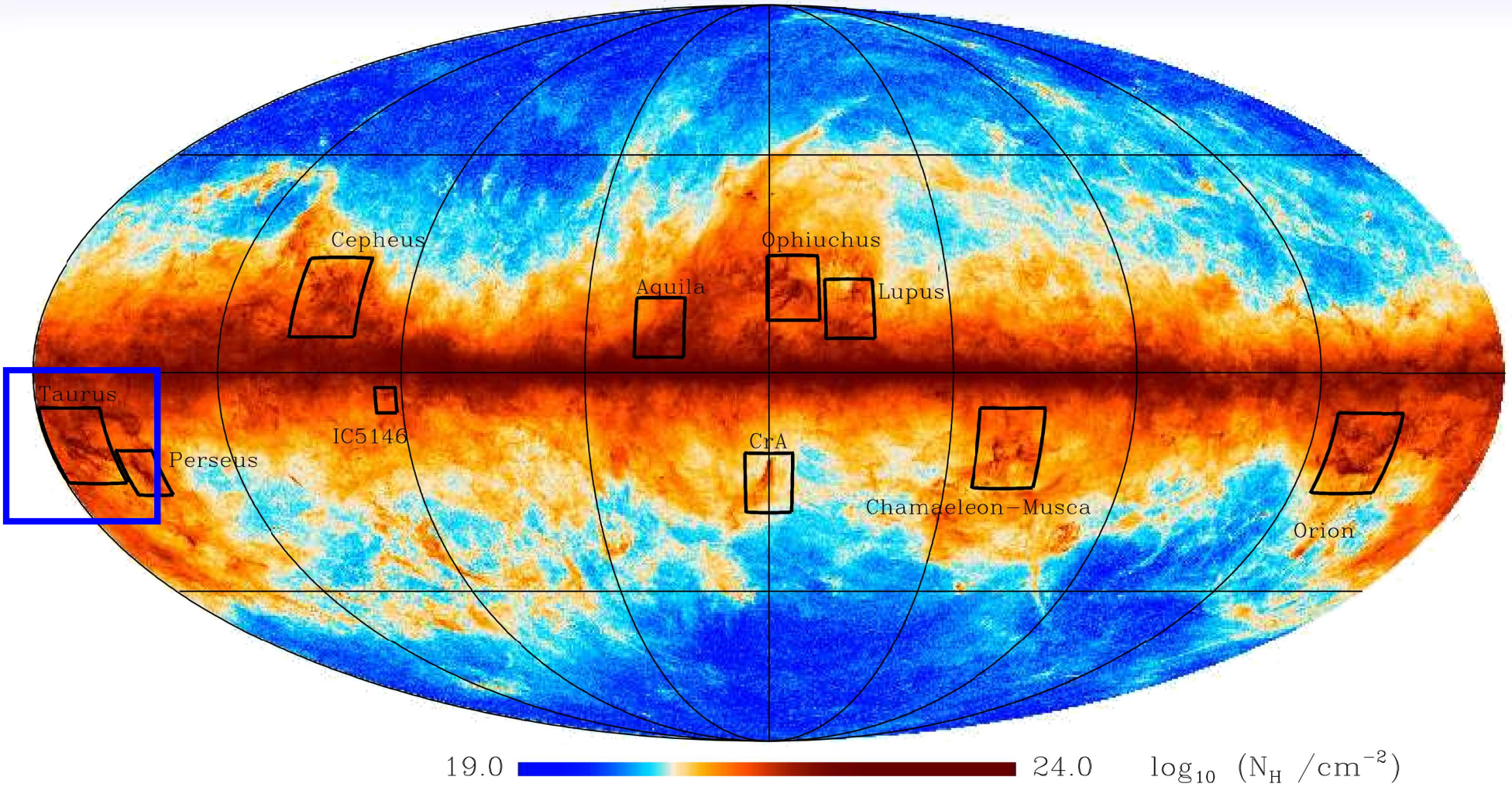
- obtain orientation of B_{pos}



Are Filaments Aligned with the Field Orientation?



(Planck Collaboration Int. XXXV 2016)

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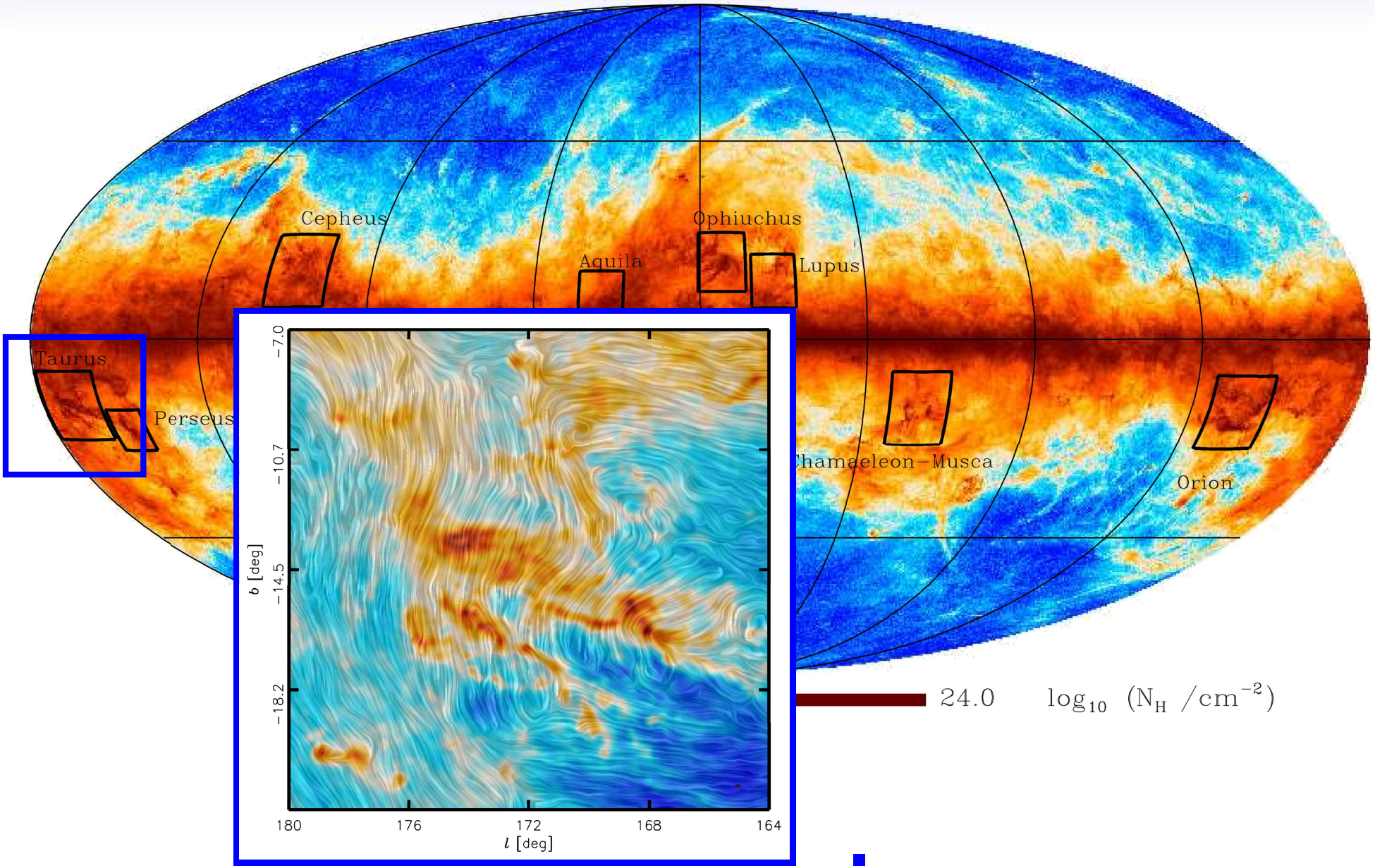

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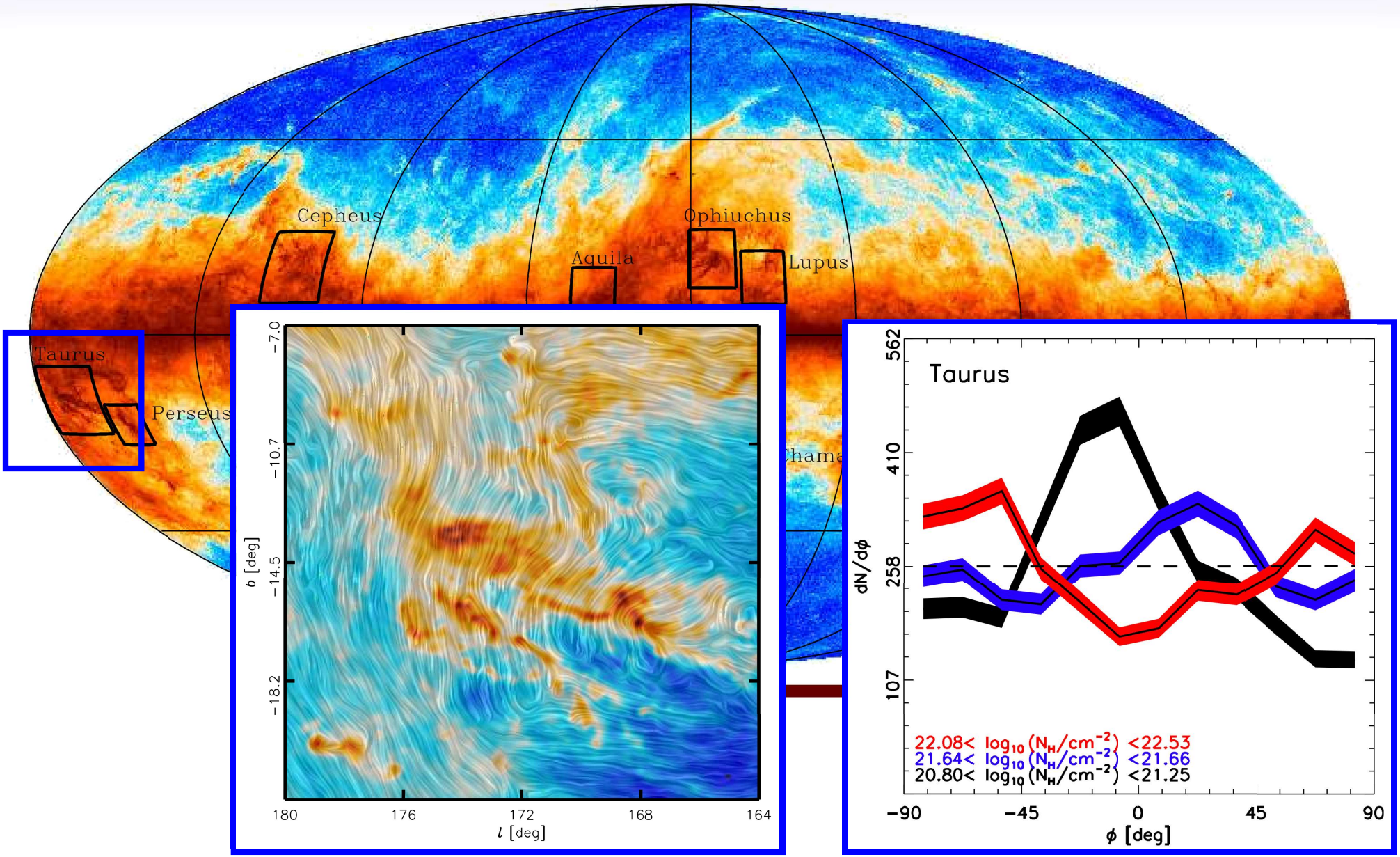

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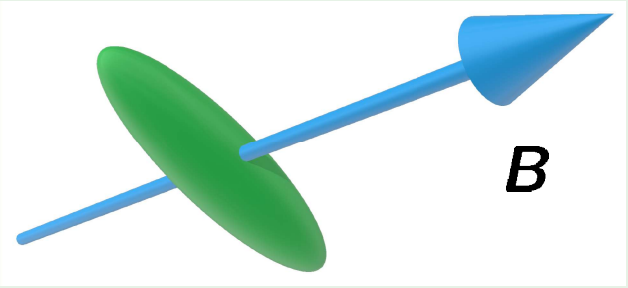

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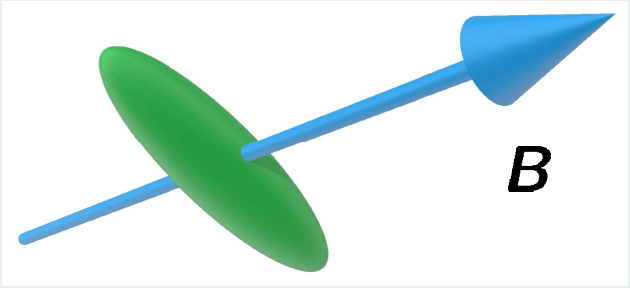

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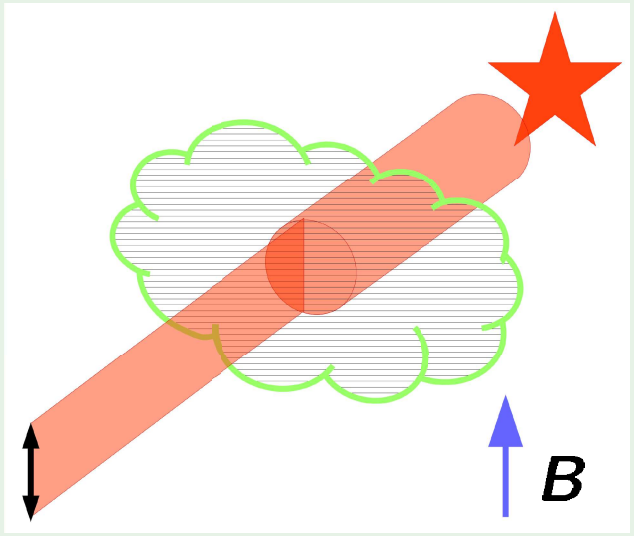
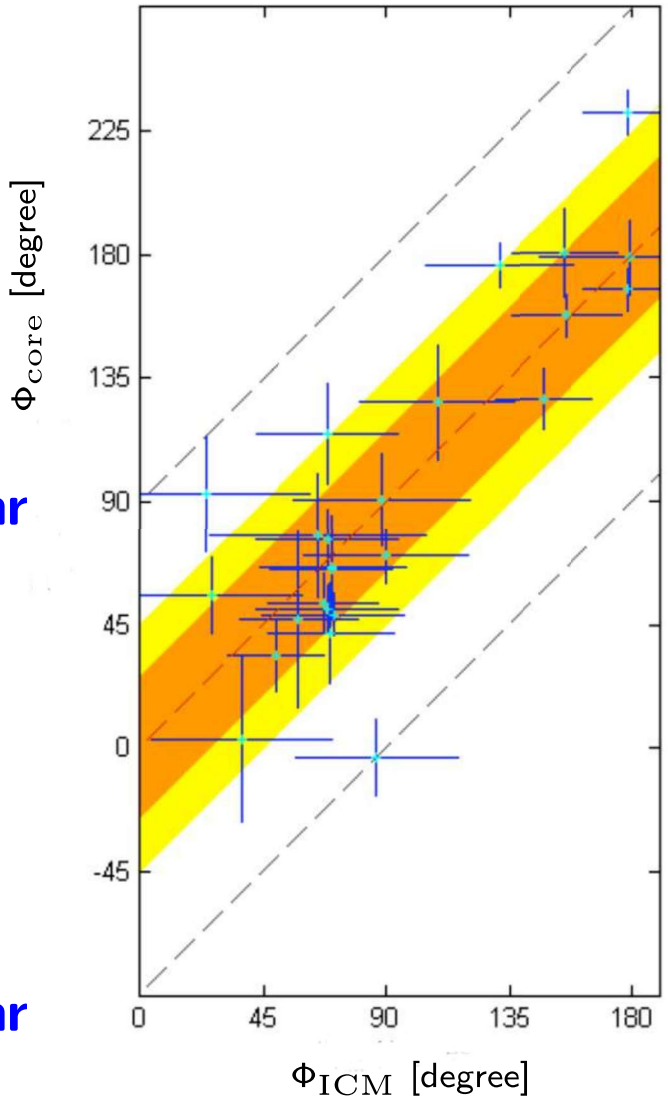


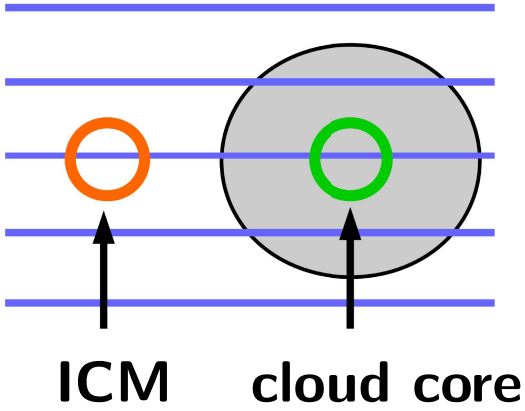
Alignment of Cloud and Inter Cloud Fields

parallel

perpendicular

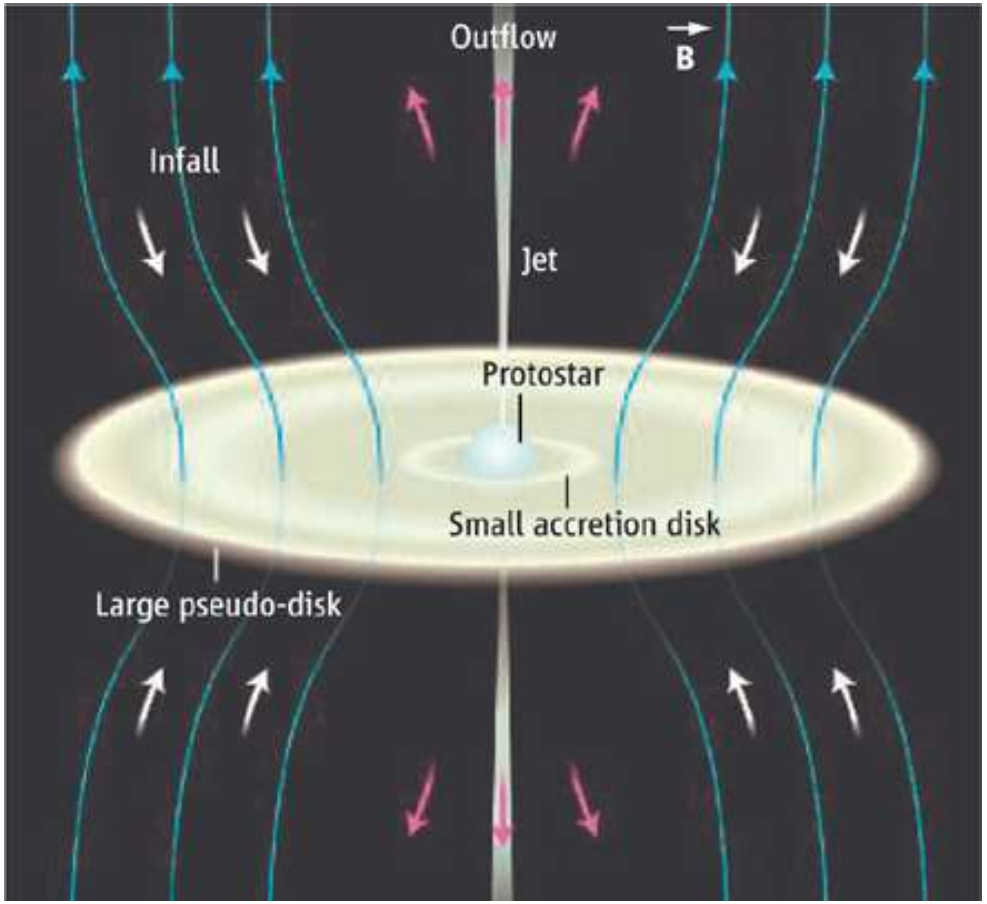


perpendicular



(Li, Goodman, et al. 2014)

Protostellar Disc Formation



(Credit: P. Huey/Science)

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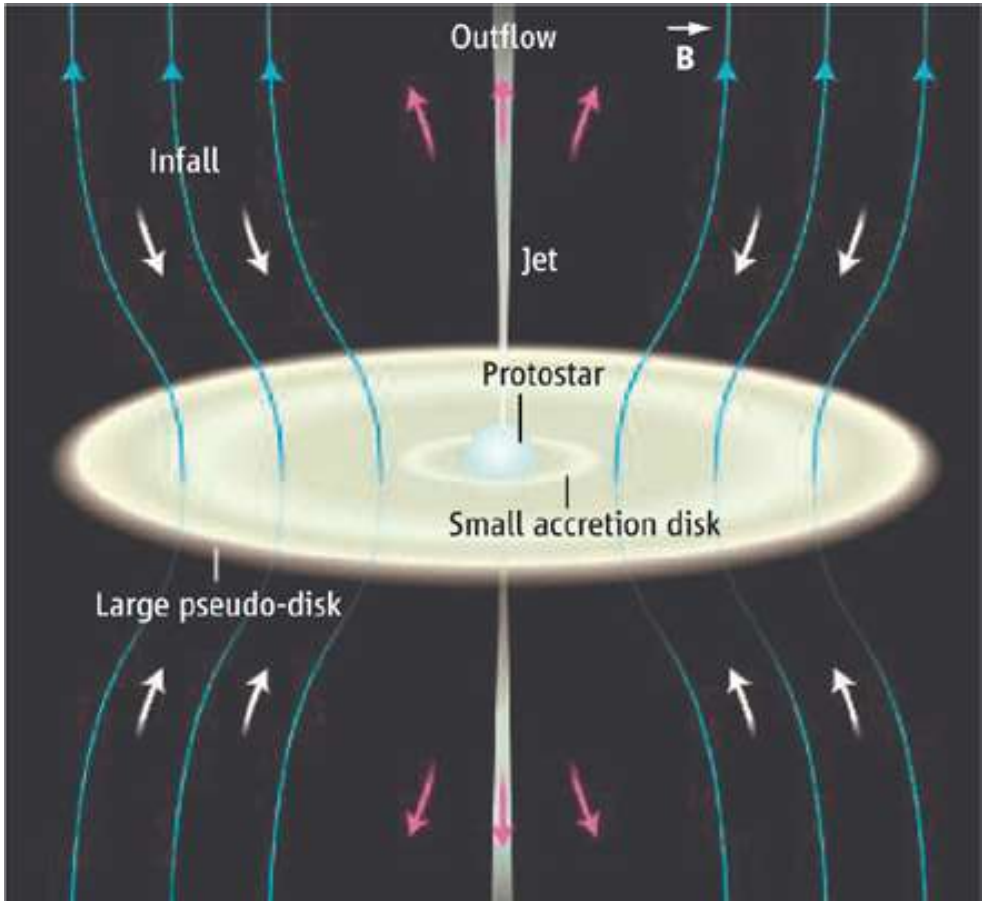

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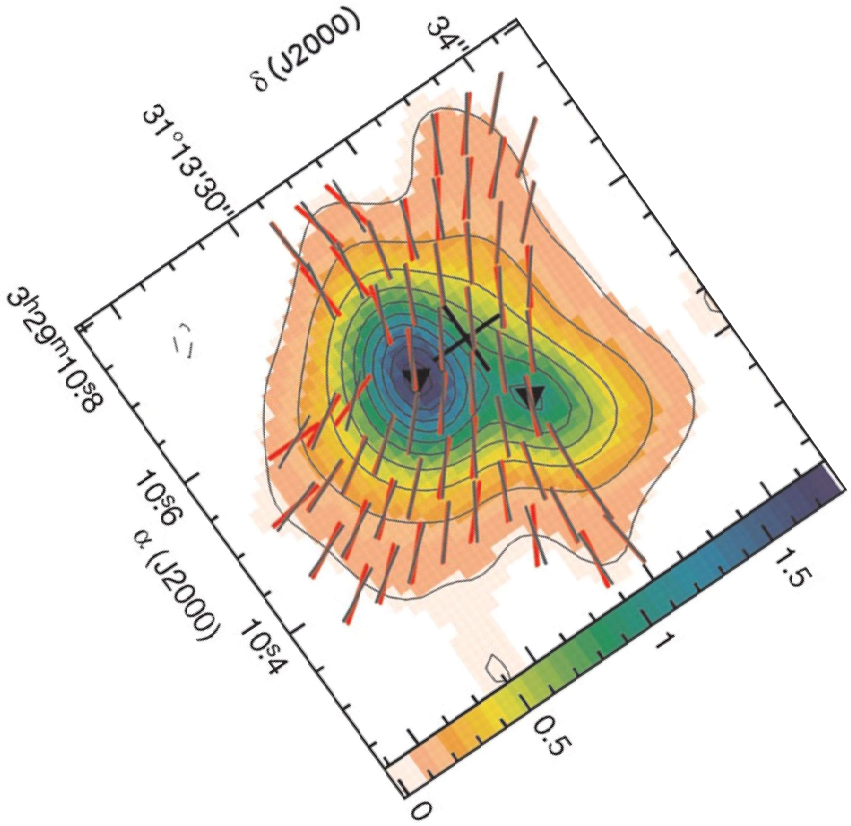
NGC 1333 IRAS 4A



(Girart, Rao, and Marrone 2006)

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- ambipolar diffusion in protostellar disc formation

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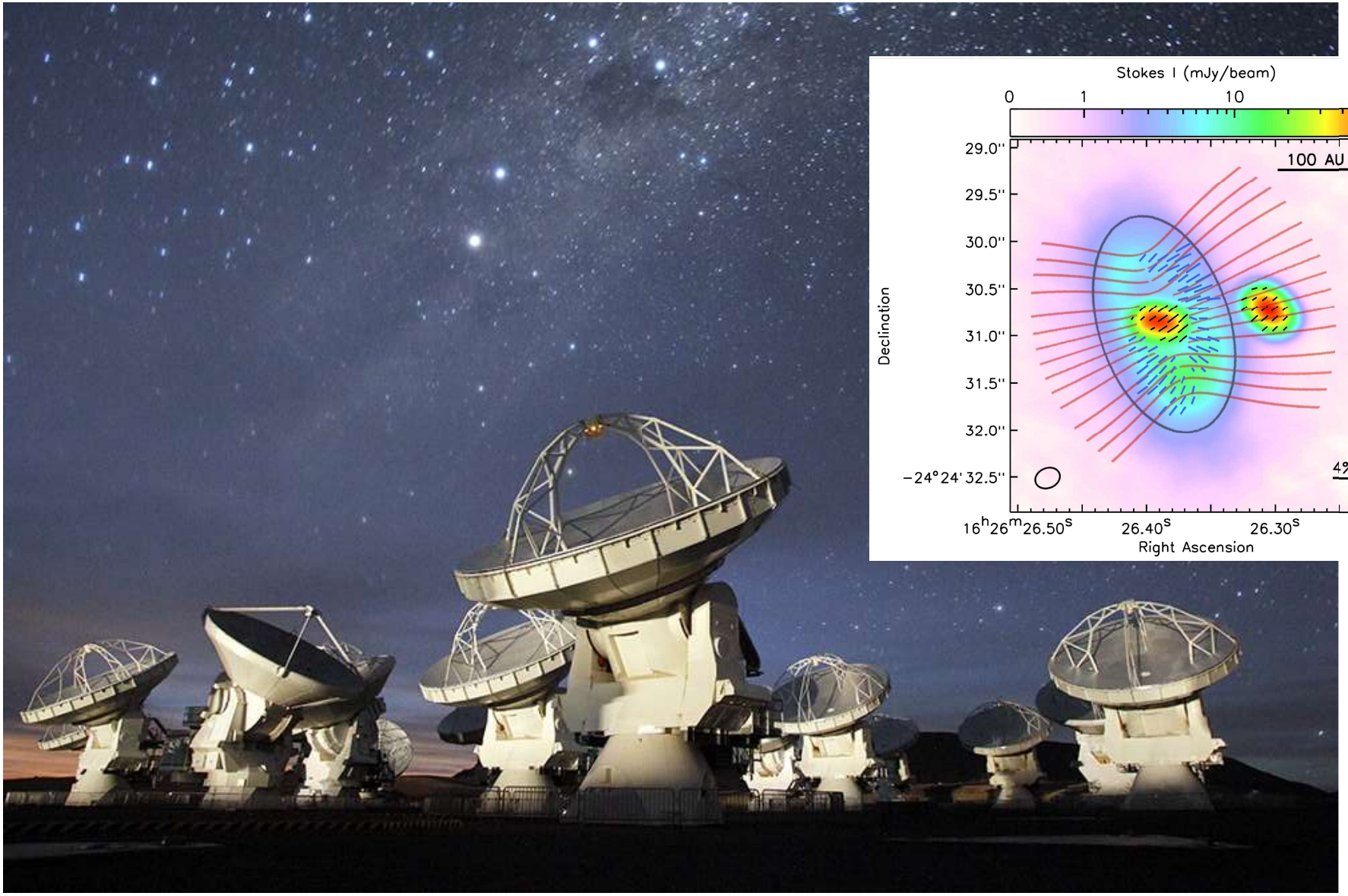
Open Questions

- 3d structure of magnetic fields in clouds
- varying conditions between clouds
- origin of galactic magnetic field
- magnetic fields on smaller scales

Outlook

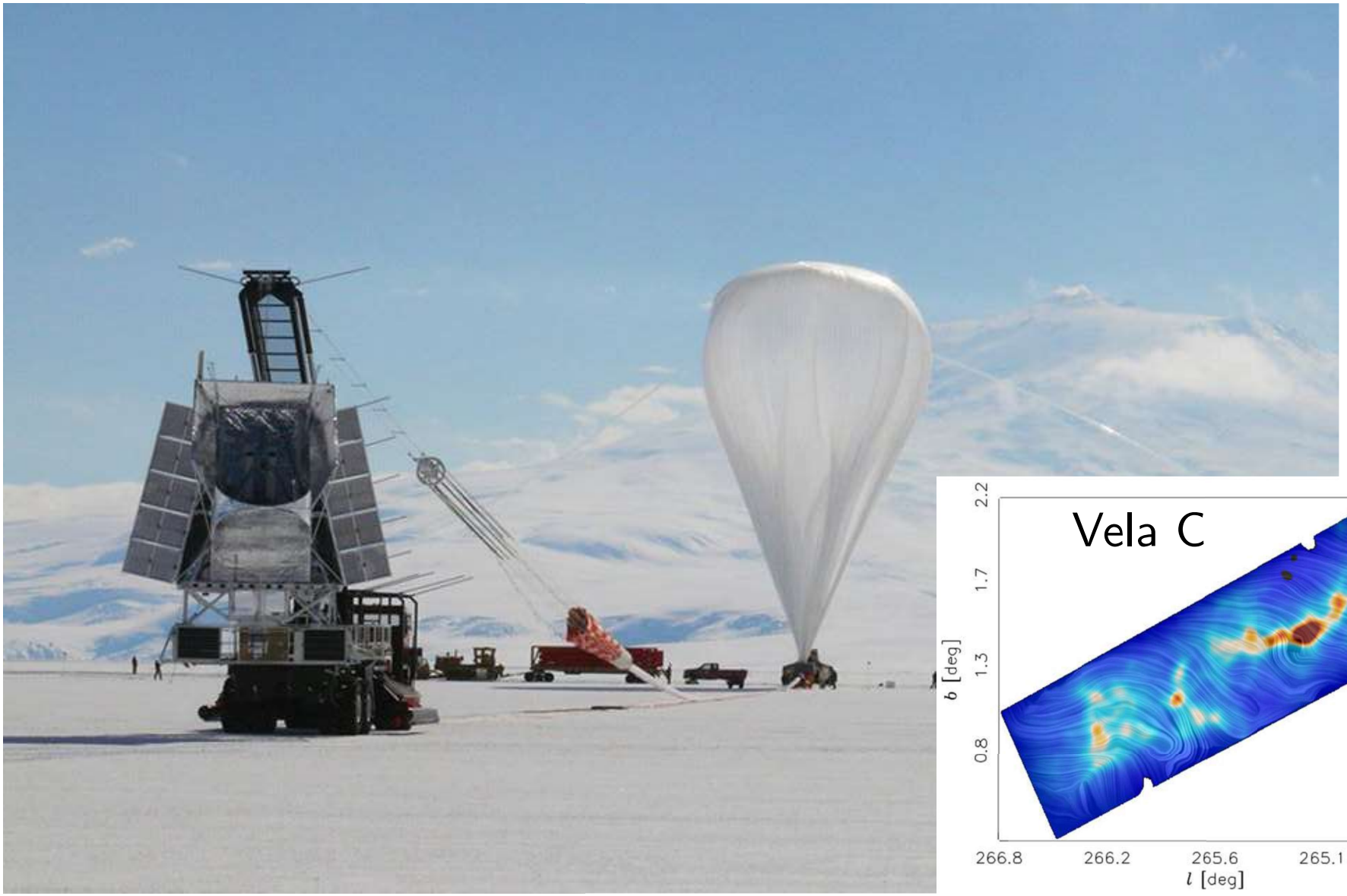
- probing small scales with ALMA



(Credit: Carlos Padilla/AUI/NRAO) *(Sadavoy et al. 2018)*

Outlook

- large scales with baloon-borne polarimetry (BLAST)



(Credit: BLAST TNG) *(Fissel et al. 2016)*

Thank you for your attention!

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