SILCC-Zoom: Simulating molecular clouds and its link to observations

Zooming in on Star Formation, Nafplio
10.6.2019

Daniel Seifried
1. Physikalisches Institut, University of Cologne

Collaborators:
Steffi Walch, Philipp Girichidis, Sebastian Haid, Richard Wünsch, Thorsten Naab

Introduction

- Challenges to model molecular clouds
    - Multi-scale physics
    - Chemical evolution

Introduction

- Challenges to model molecular clouds
    - Multi-scale physics
    - Chemical evolution

- Challenges in theory:
    - molecular cloud turbulence
    - magnetic fields

Introduction

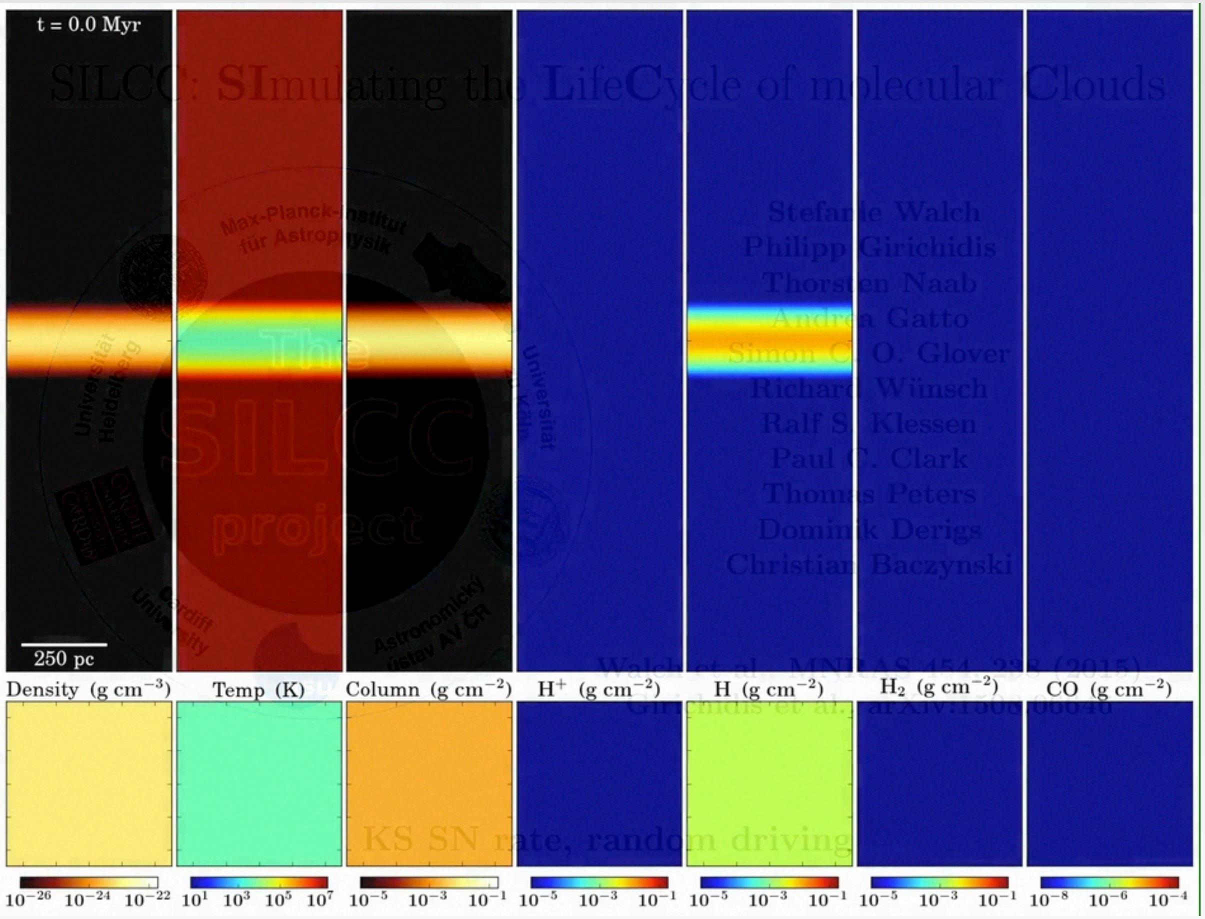
- Challenges to model molecular clouds
    - Multi-scale physics
    - Chemical evolution

- Challenges in theory:
    - molecular cloud turbulence
    - magnetic fields

- Challenges to observe
    - Dust polarisation
    - not yet fully understood: what, how?
    - Ongoing research (e.g. BlastPol)

SILCC-Zoom: Numerics

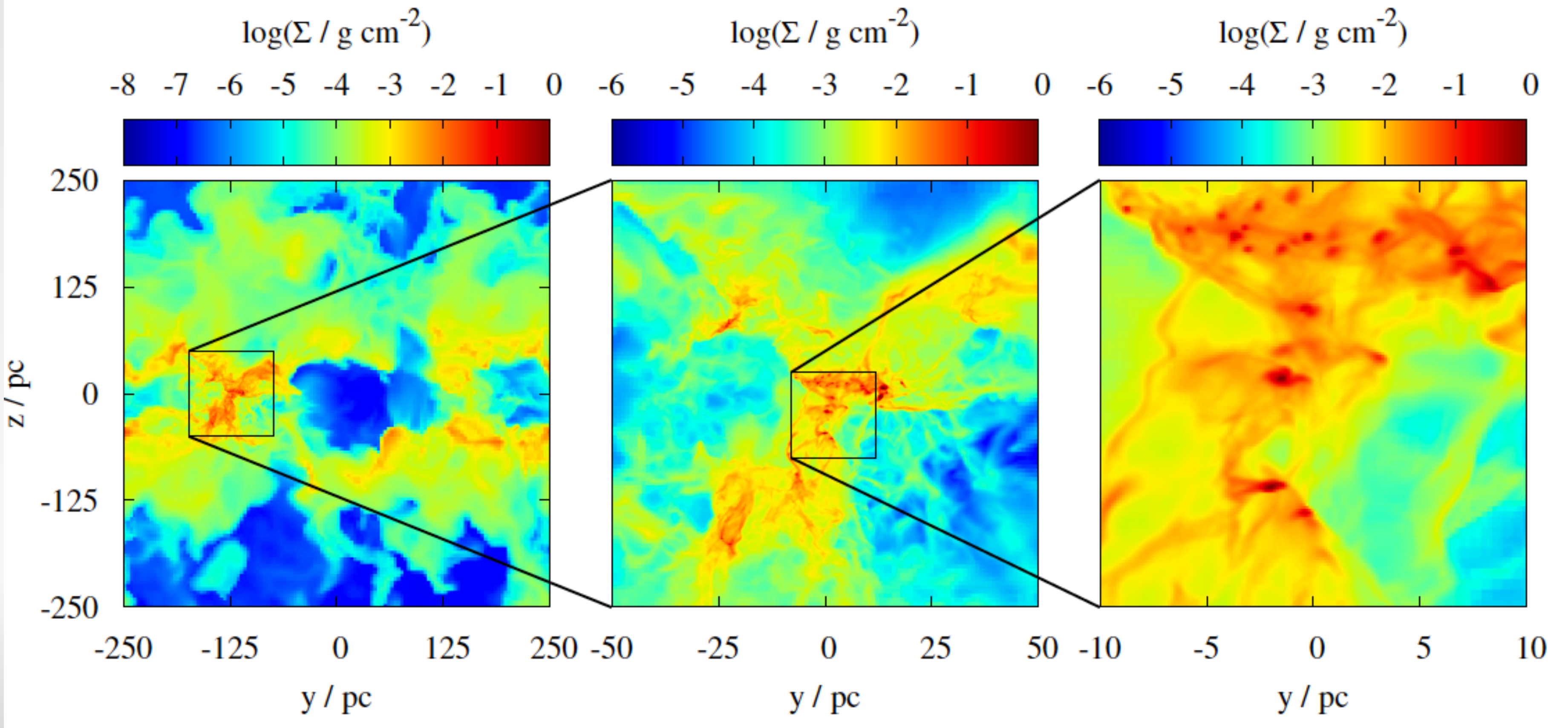
- Simulations based on the SILCC simulations (Walch et al. 2015, Girichidis et al. 2016)
- part of a galactic disk
- Supernova driving
- Network for H_2 and CO chemistry
- Varying magnetic field strengths



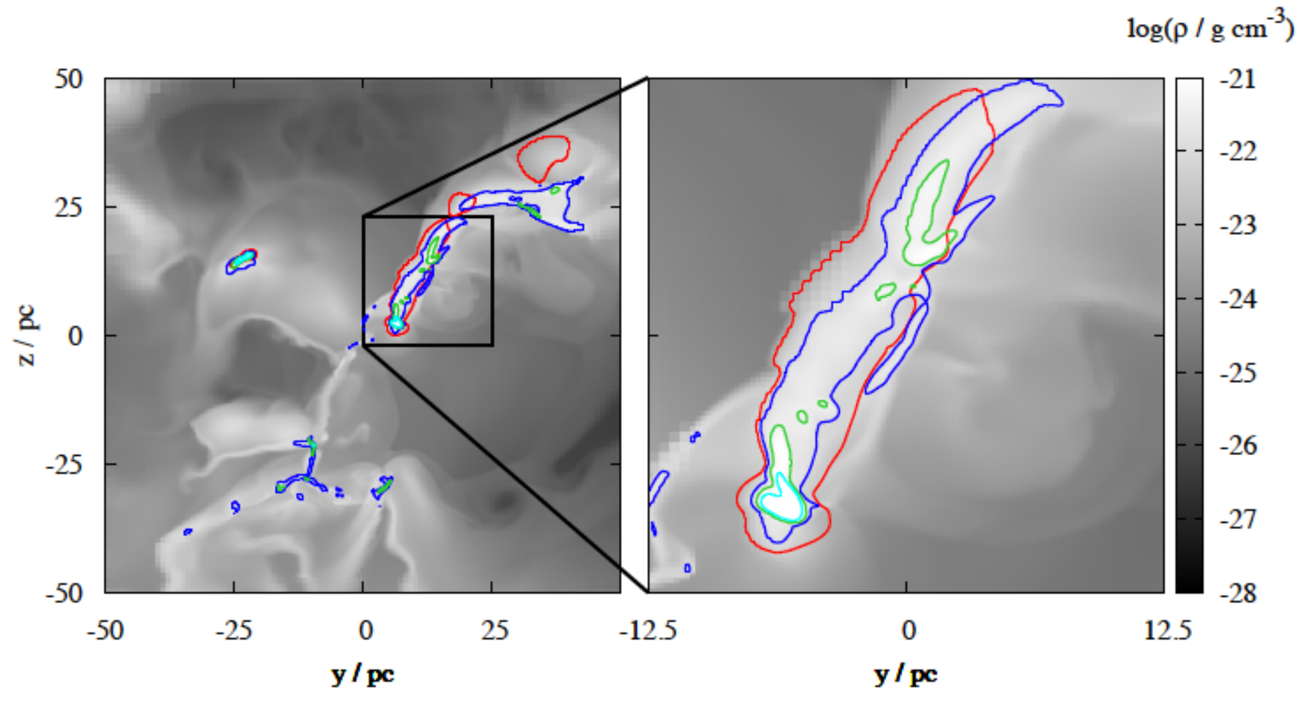
Zoom-in procedure

- We select regions in which MCs are about to form (about 50-100 pc in size)
- We increase the resolution from 4 pc to ~ **0.1 pc**

Seifried et al., 2017, MNRAS, 472, 4797

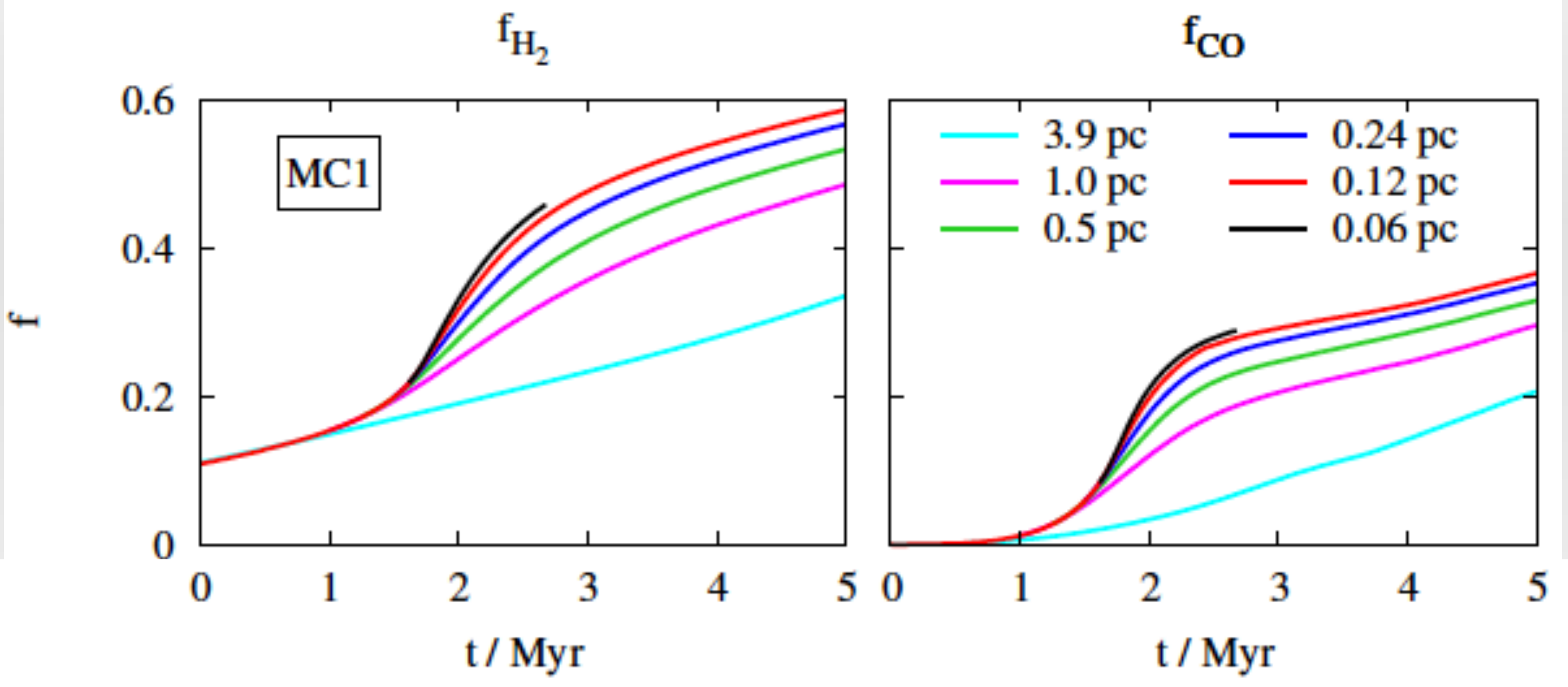


Chemical composition: H_2



- H_2 (red line) present in lower density gas $n < 30$ cm^{-3} (blue line)
- H_2 formation time scale ~ 30 Myr >> simulated time (a few Myr)
  - Turbulent mixing from dense regions into low-density gas (Glover et al. 2010, Valdivia et al. 2016)
  - Non-equilibrium chemistry
  - Simple chemical postprocessing NOT possible for H_2

Chemical composition: Convergence



Seifried et al., 2017, MNRAS, 472, 4797

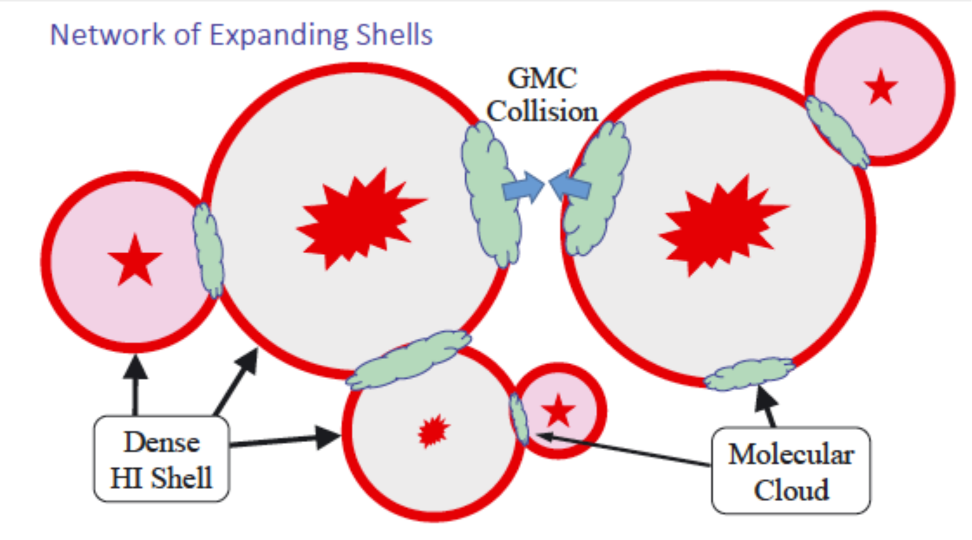
Joshi et al. 2019, MNRAS, 484, 1735

- H_2 and CO content converge at **~ 0.1 pc**
- Supported by **analytical** model (Joshi et al. 2019)
- Essential for synthetic observations

Turbulence in MCs

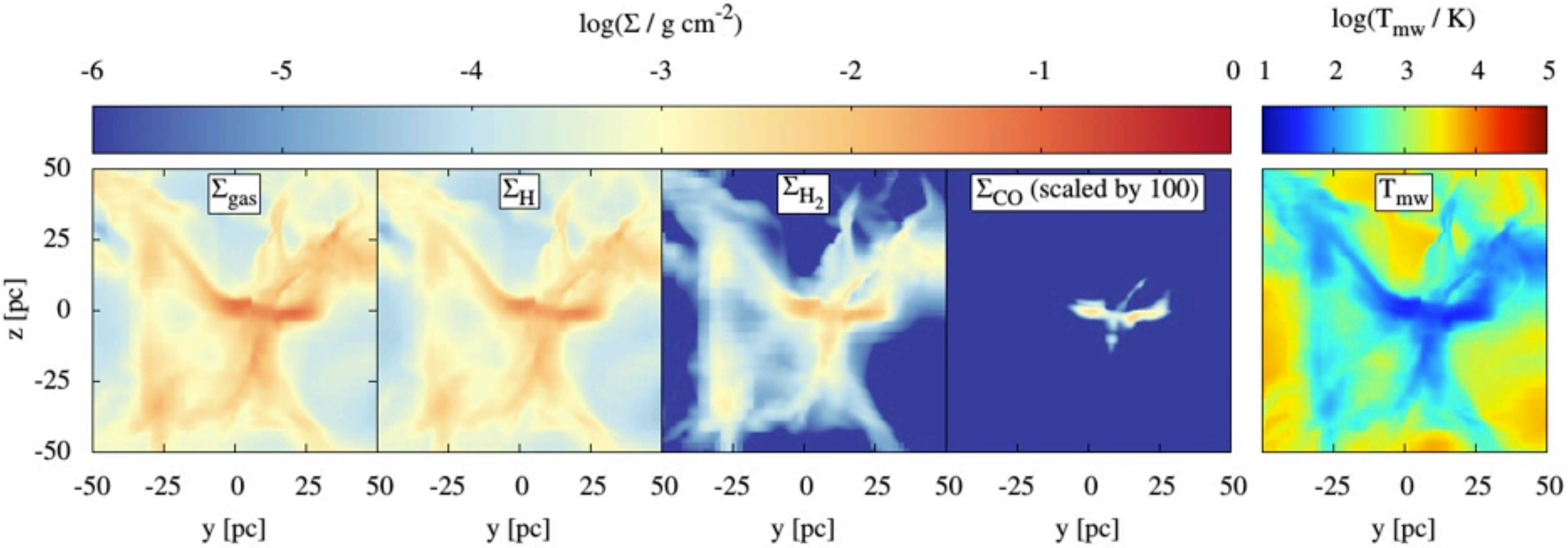
- Supernovae (SNe)
  - drive turbulence in the diffuse ISM
  - create MCs at collision interfaces (Koyama & Inutsuka 2000)
  - maintain turbulence later-on? (see talk by Paolo Padoan)

- Impact of gravity in maintaining turbulence? (Ibanez-Mejia et al. 2016, 2017)



Inutsuka et al. 2014

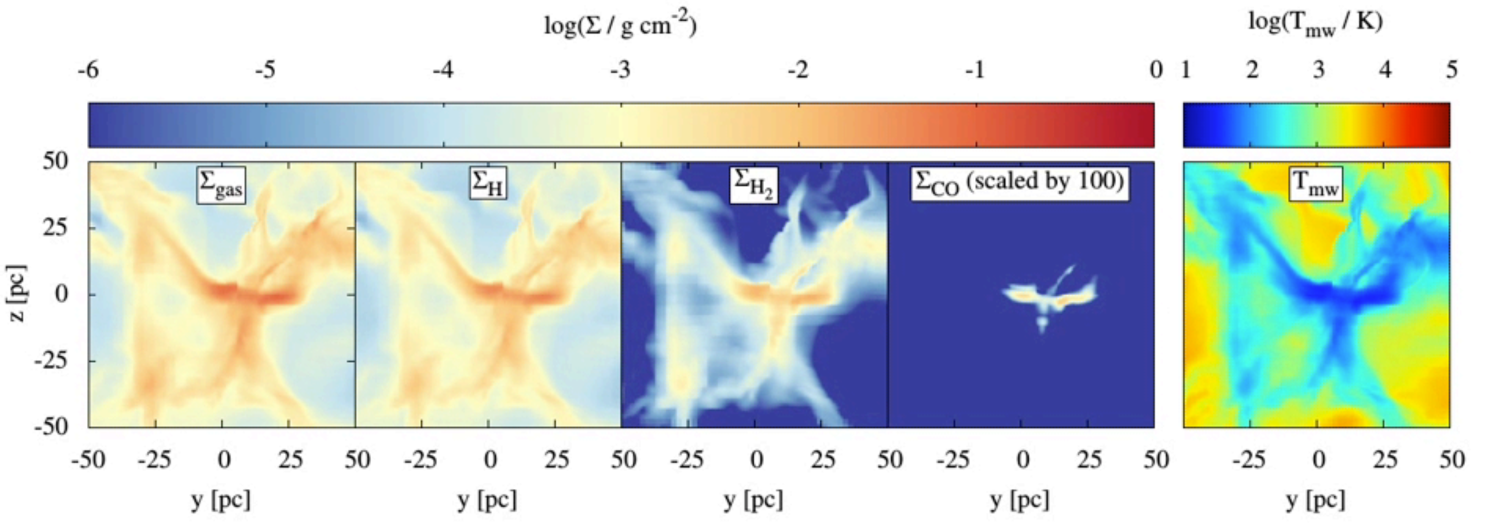
Turbulence in MCs



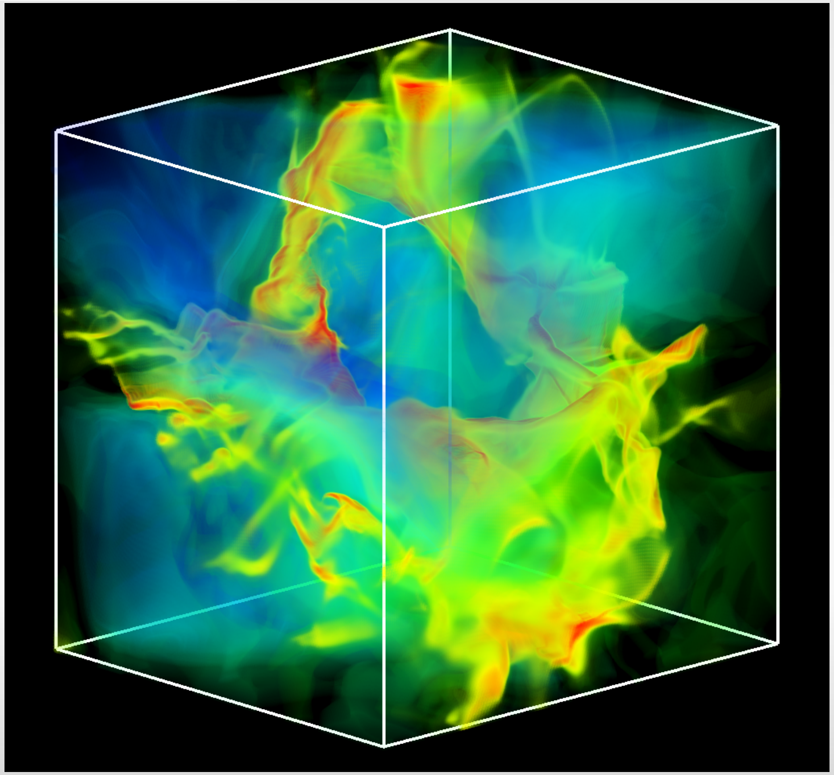
Seifried et al. 2018, ApJ, 885, 81

- SN exploding 25 pc away from a MC
    - Dense parts of MC little affected
    - SN is „channeling“ through the cloud

Turbulence in MCs

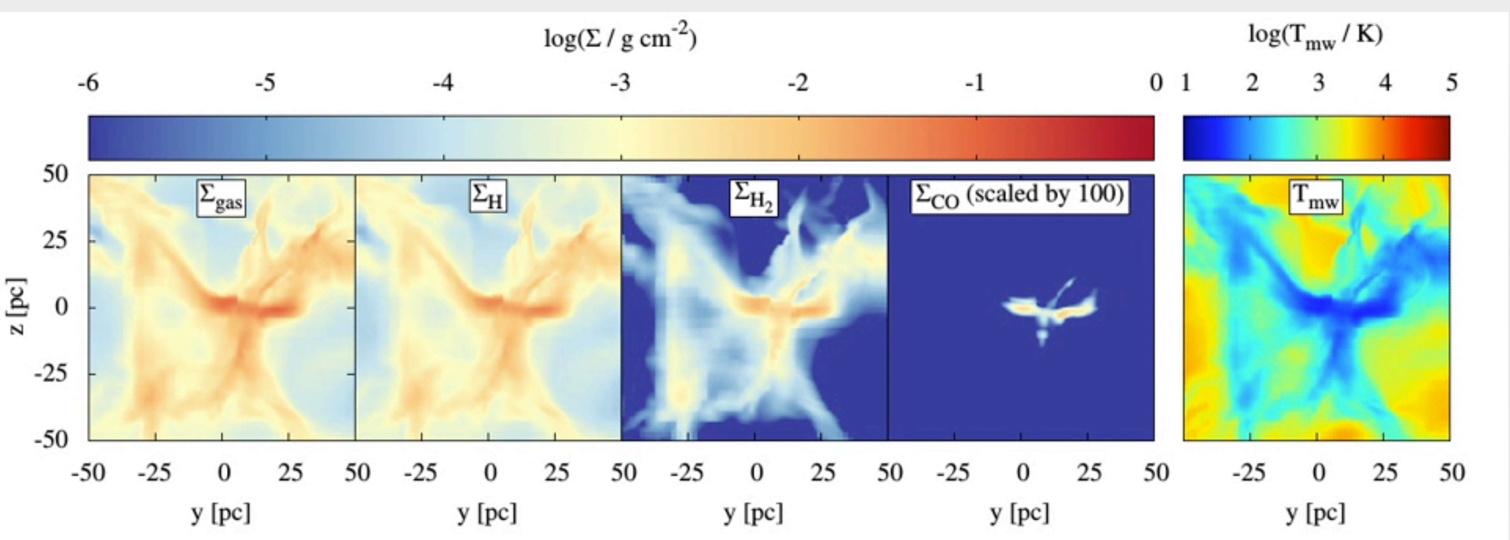


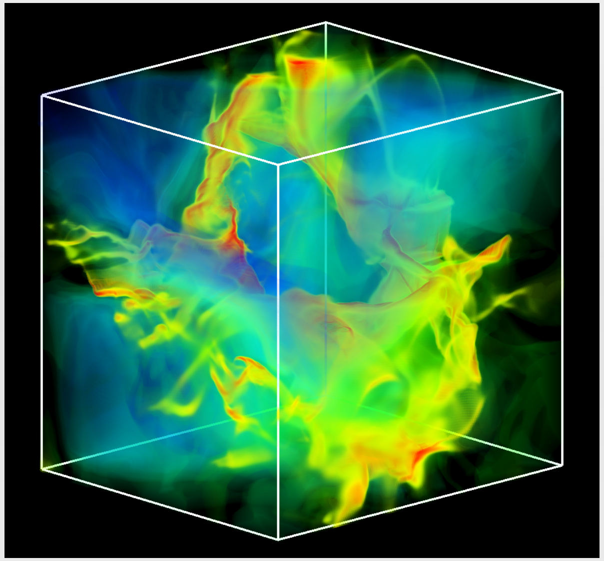
Seifried et al. 2018, ApJ, 885, 81



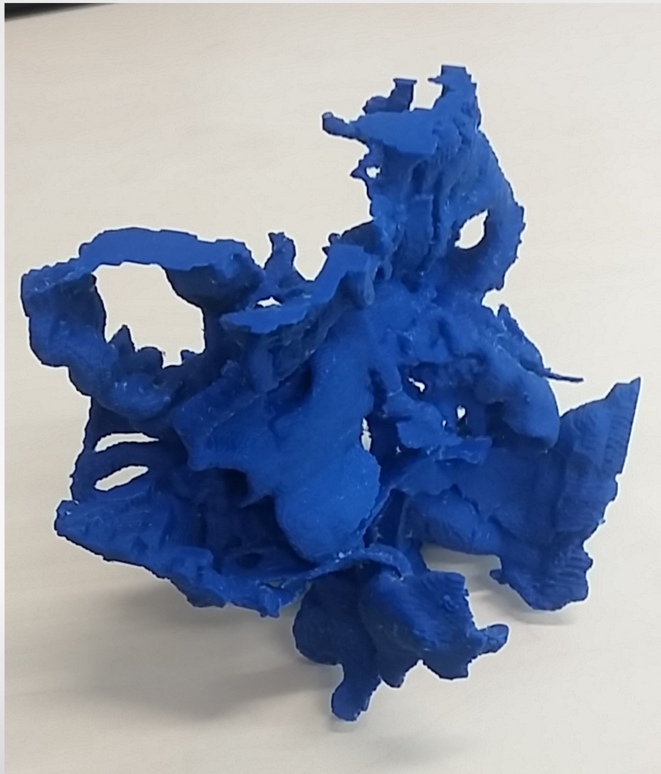
- SN exploding 25 pc away from a MC
  - Dense parts of MC little affected
  - SN is „channeling“ through the cloud
  - highly filamentary structure
  - → a MC is NOT a sphere

Turbulence in MCs





Seifried et al. 2018, ApJ, 885, 81



- SN exploding 25 pc away from a MC
  - Dense parts of MC little affected
  - SN is „channeling“ through the cloud
  - highly filamentary structure
  - → a MC is NOT a sphere

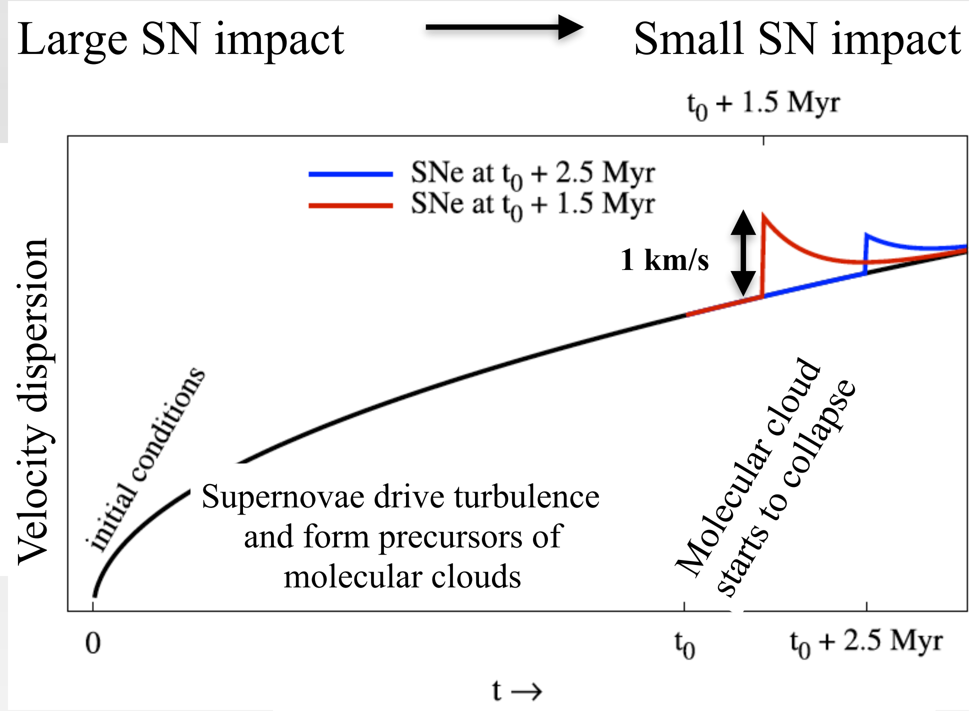
Supernova driven turbulence

- Decay of turbulence within a few 100 kyr
- the late the SNe, the lower its effect
    - „cross section“ decreases

- Under solar neighborhood conditions:
    - MC relatively inert against external SN during collapse
    - ⇒ Turbulence driving not possible

- In CMZ:
    - SNe more frequent
    - ⇒ Turbulence driving by SN possible

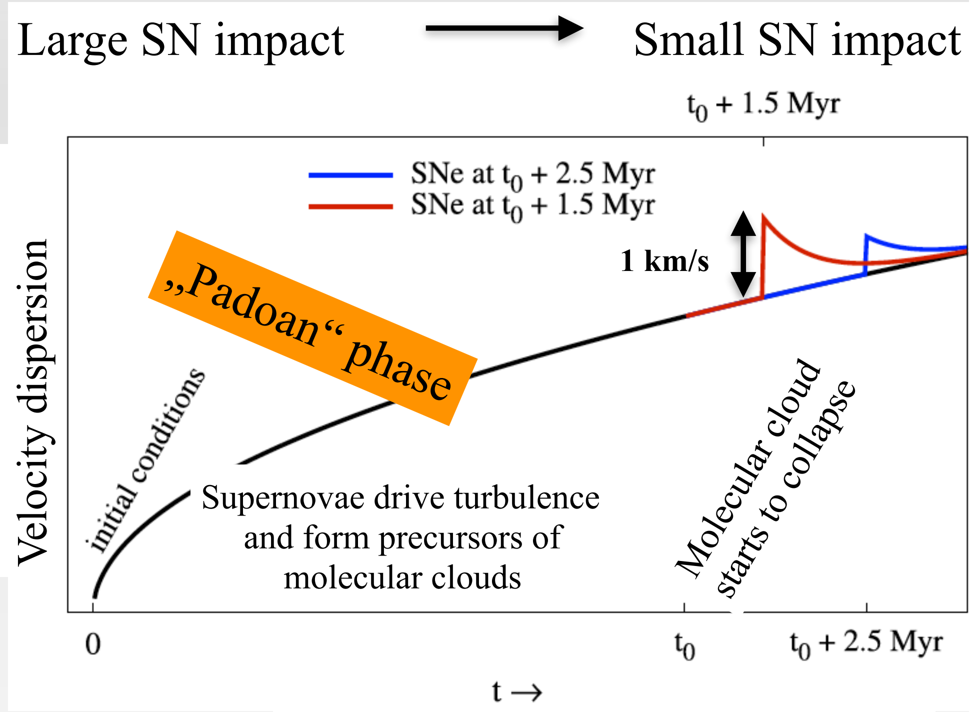
      (Kauffmann et al. 2017)



Seifried et al. 2018, ApJ, 885, 81

Supernova driven turbulence

- Decay of turbulence within a few 100 kyr
- the late the SNe, the lower its effect
    - „cross section“ decreases
- Under solar neighborhood conditions:
    - MC relatively inert against external SN during collapse
    - ⇒ Turbulence driving not possible
- In CMZ:
    - SNe more frequent
    - ⇒ Turbulence driving by SN possible (Kauffmann et al. 2017)

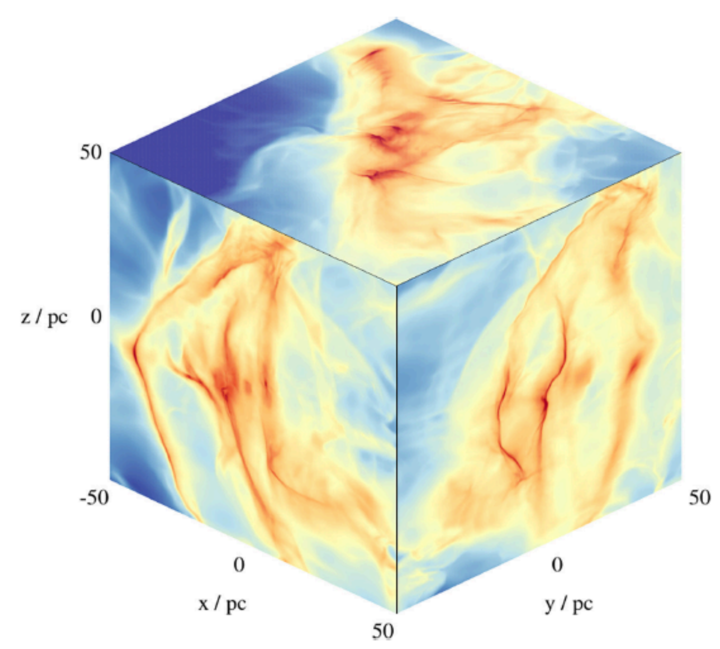


Seifried et al. 2018, ApJ, 885, 81

Polarisation radiative transfer

- Combine MHD simulation of MCs with POLARIS (Reissl et al., 2016)

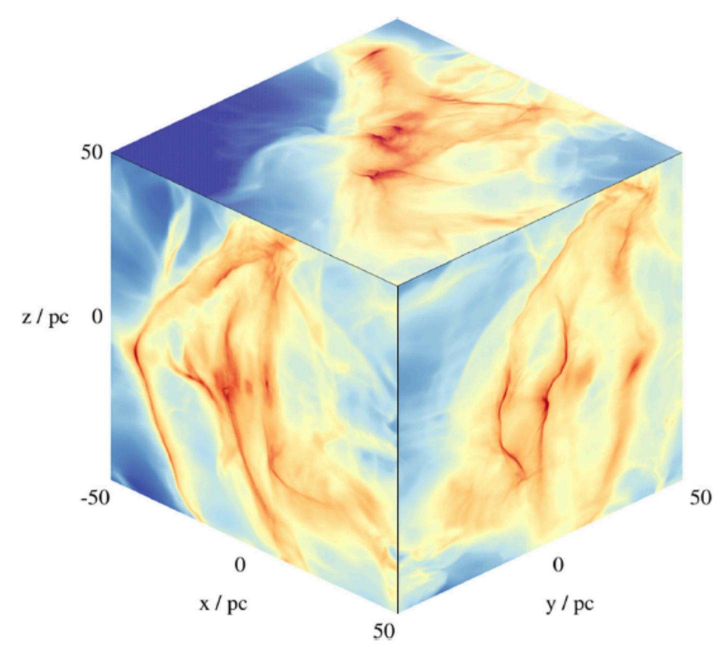
- Fully self-consistent dust polarisation radiative transfer:
    - Application of Radiative torque (RAT) alignment theory (Lazarian & Hoang 2007)
    - Standard dust model (size: 5 nm - 2 µm, $a^{-3.5}$)



Seifried et al., 2019, MNRAS, 482, 2697

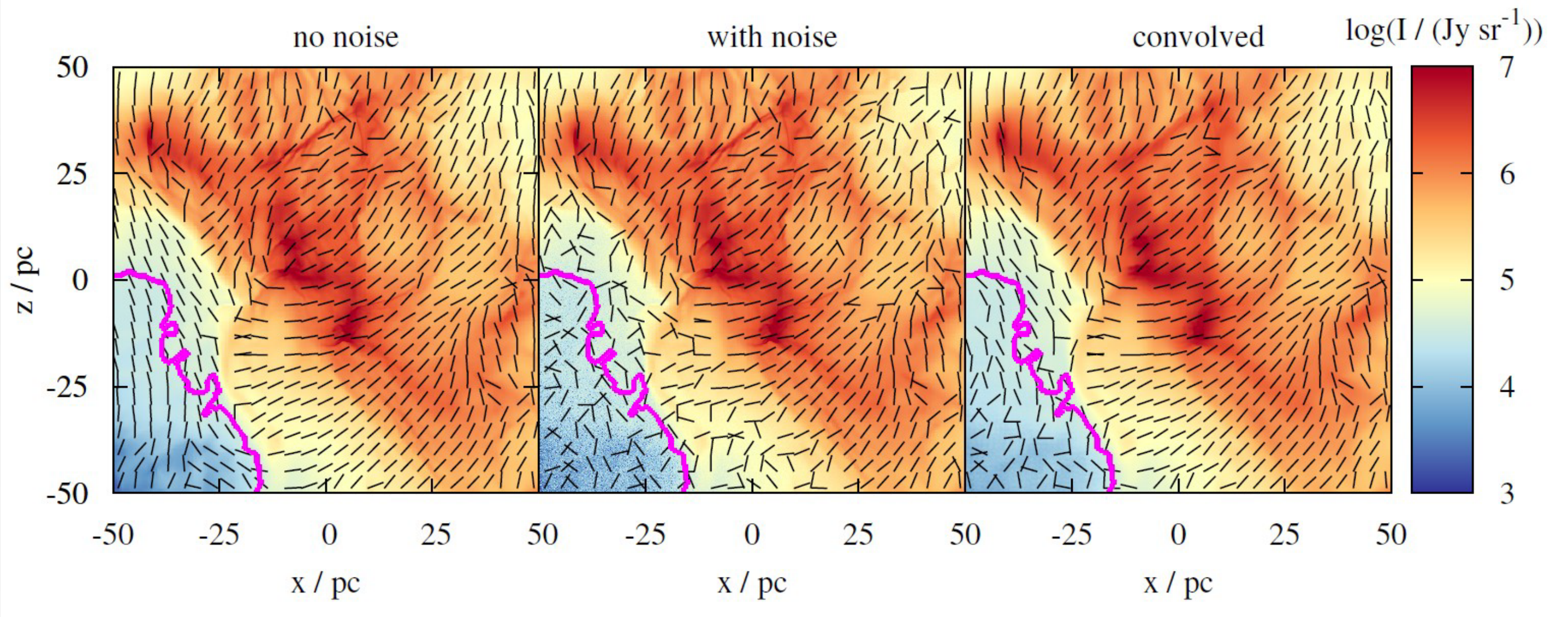
Polarisation radiative transfer

- Combine MHD simulation of MCs with POLARIS (Reissl et al., 2016)
- Fully self-consistent dust polarisation radiative transfer:
  - Application of Radiative torque (RAT) alignment theory (Lazarian & Hoang 2007)
  - Standard dust model (size: 5 nm - 2 µm, $a^{-3.5}$)
- λ = 70.4, 161, 243, 342, 515, 850, 1300, and 3000 µm
- Including realistic noise
  - adapted to typical Planck/BlastPol observations



Seifried et al., 2019, MNRAS, 482, 2697

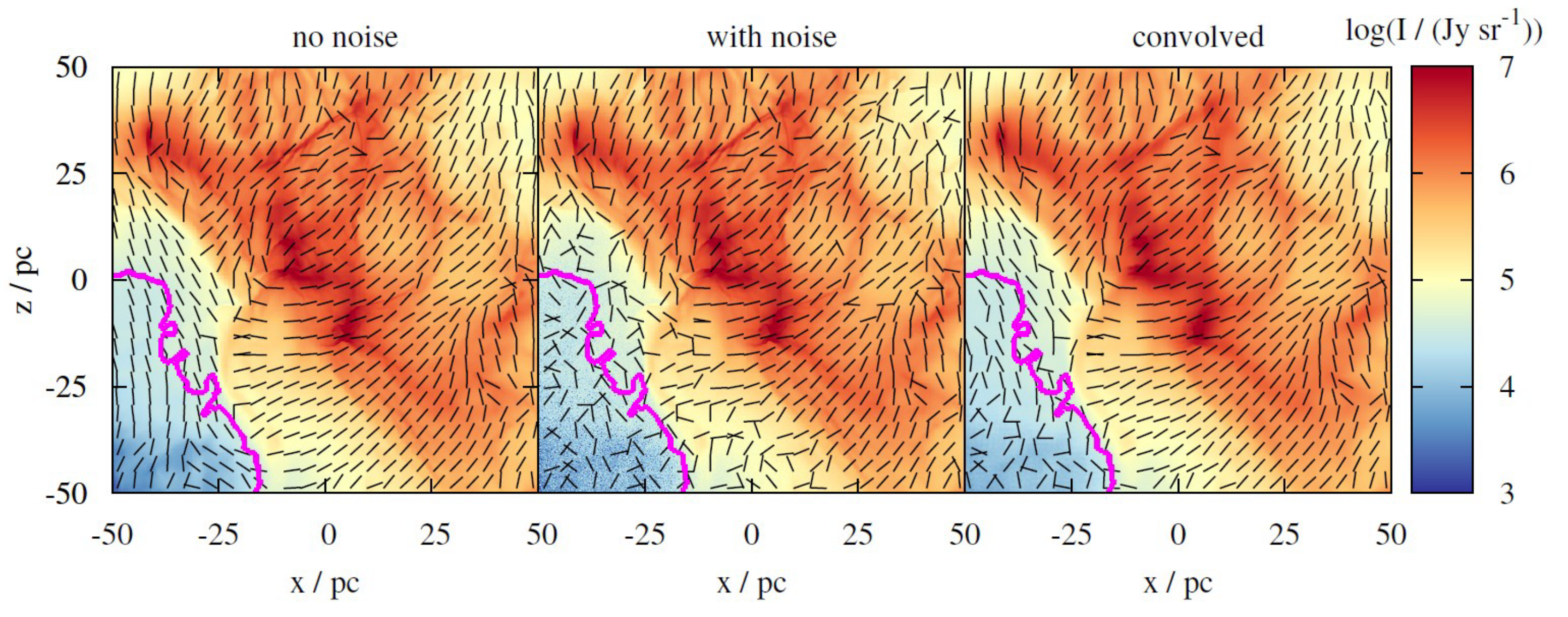
The influence of noise



Seifried et al., 2019, MNRAS, 482, 2697

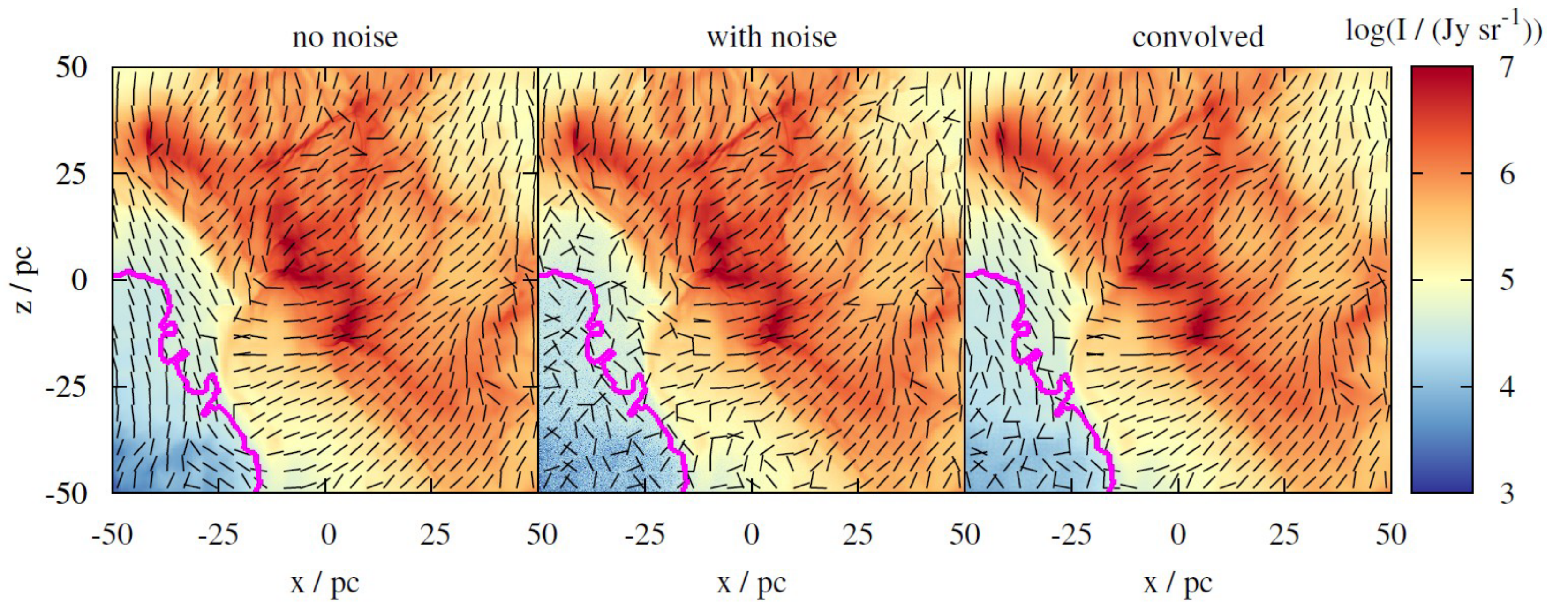
- Randomizes polarisation vectors in low-intensity regions
- Convolution improves quality
- Large deviations below
  - 1 M_{sun} pc^{-2} , A_V ~ 0.1
  - intensities below 3 x noise level

Which regions are traced by dust polarisation?



Seifried et al., 2019, MNRAS, 482, 2697

Which regions are traced by dust polarisation?

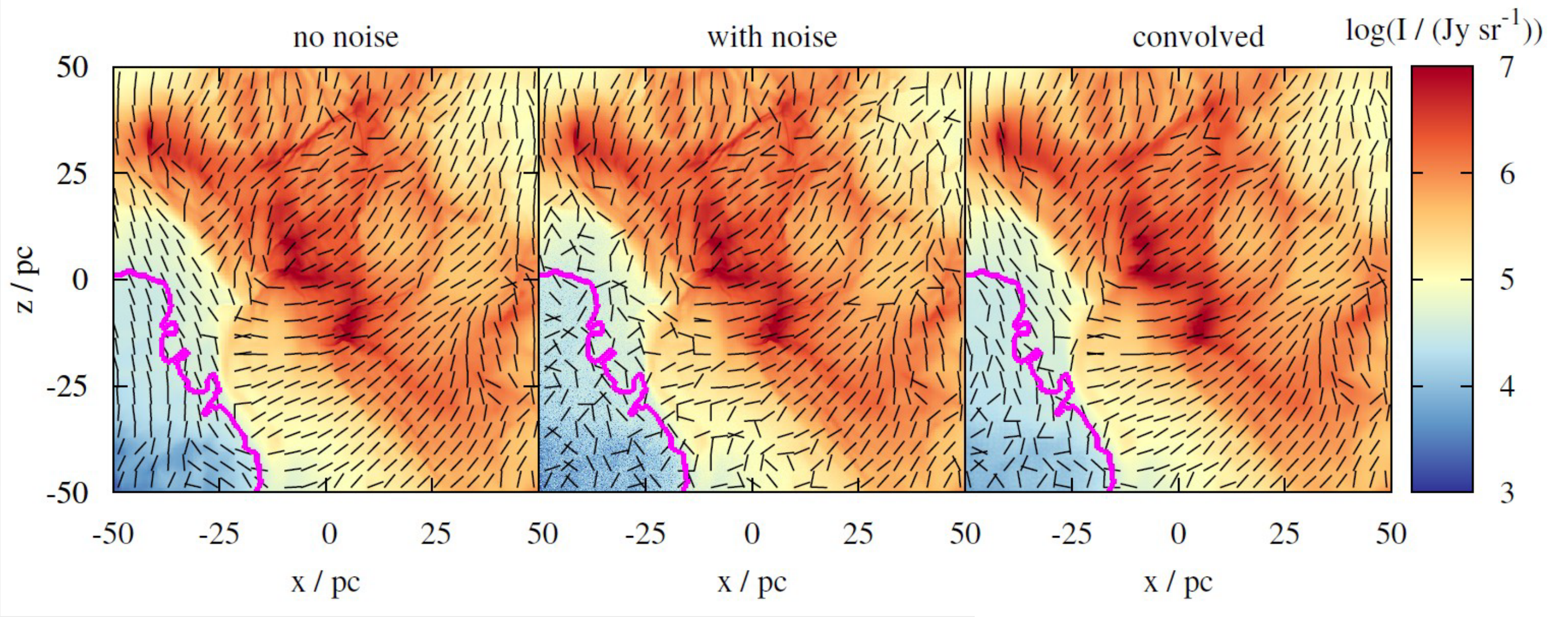


Seifried et al., 2019, MNRAS, 482, 2697

- Comparison dust polarisation <-> LOS-averaged magnetic field:

$$\mathbf{B}_{\mathrm{mw}} = \frac{\int_{\mathrm{LOS}} \rho\, \mathbf{B}\, \mathrm{d}l}{\int_{\mathrm{LOS}} \rho\, \mathrm{d}l}$$

Which regions are traced by dust polarisation?



Seifried et al., 2019, MNRAS, 482, 2697

- Comparison dust polarisation <-> LOS-averaged magnetic field:

$$\mathbf{B}_{\mathrm{mw}} = \frac{\int_{\mathrm{LOS}} \rho\, \mathbf{B}\, \mathrm{d}l}{\int_{\mathrm{LOS}} \rho\, \mathrm{d}l}$$

  - Accuracy of field measurement: **≤ 5º**
  - ⟹ Dust polarisation probes dense structures
  - ⟹ Less the diffuse foreground/background

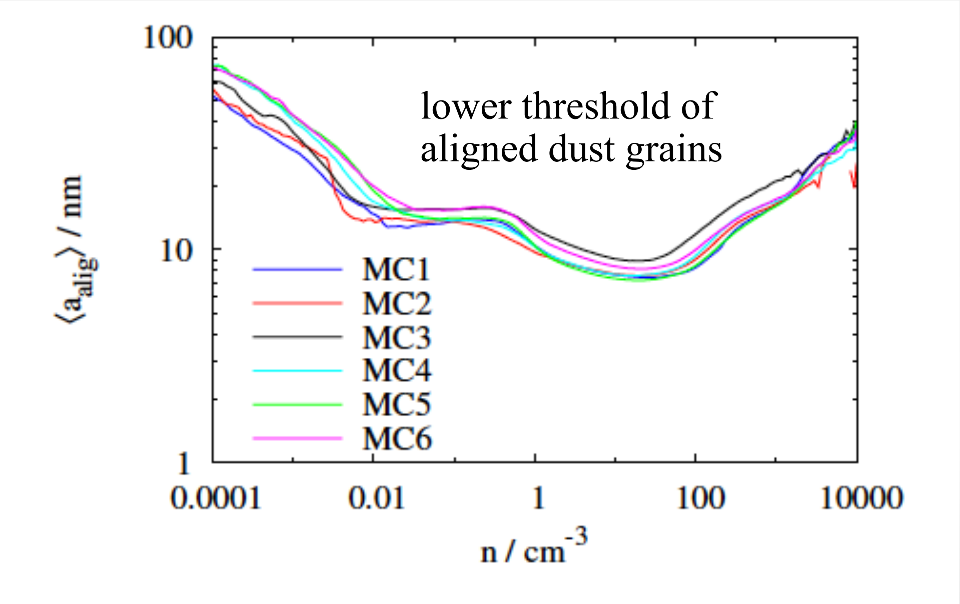
Which regions are traced by dust polarisation?

- Dust polarisation probes dense structures:
- $\Longrightarrow$ Dust alignment effective in dense, well-shielded regions?!
  - Requires sufficient radiation

Which regions are traced by dust polarisation?

- Dust polarisation probes dense structures:
- ⟹ Dust alignment effective in dense, well-shielded regions?!
  - Requires sufficient radiation

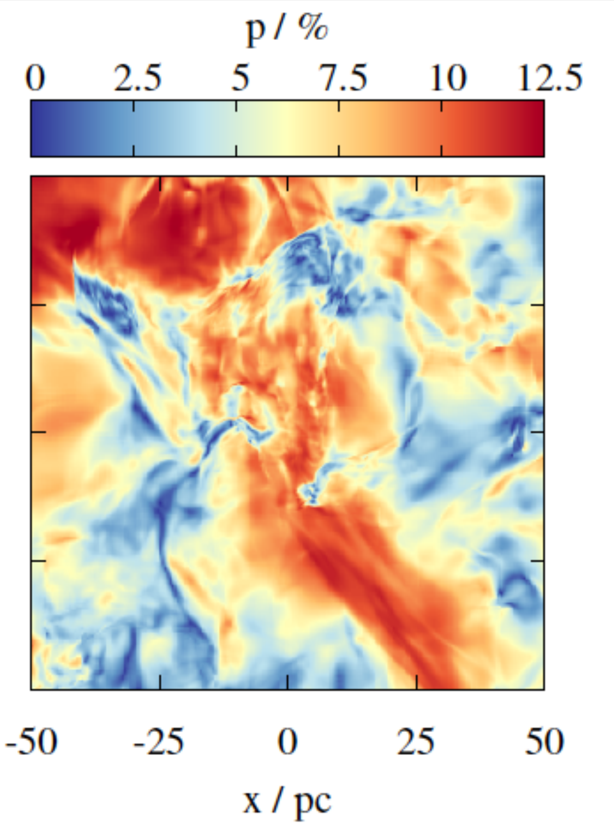
- POLARIS: dust size-dependent information about alignment:
  - smallest grains well aligned up to n ~ 1000 cm^{-3} (~ $A_V > 3$)
  - RAT still efficient
  - Potential decrease towards higher densities
  - ⇒ depolarisation in very dense cores (no resolved here)



Depolarisation

- Polarisation observations show depolarization
  - Also visible in simulations

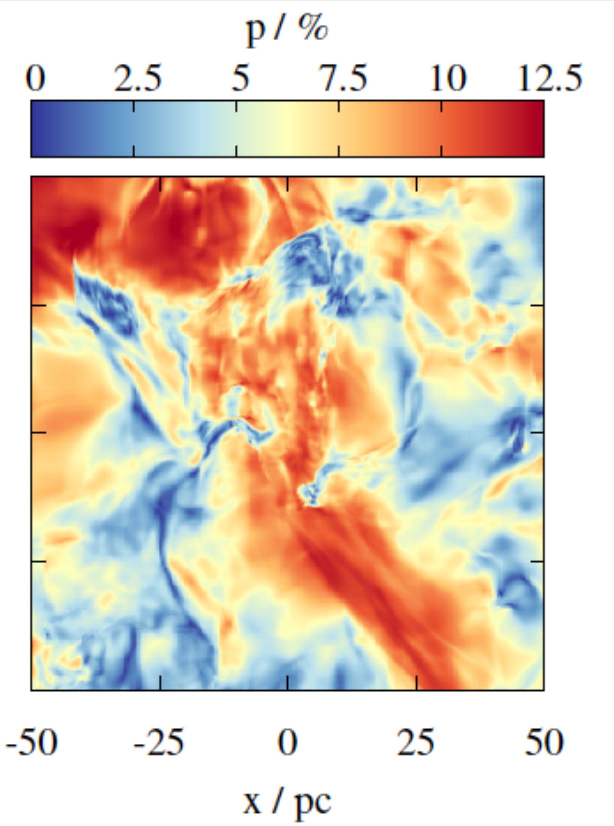
- Strongly tangled fields as a source of depolarization?

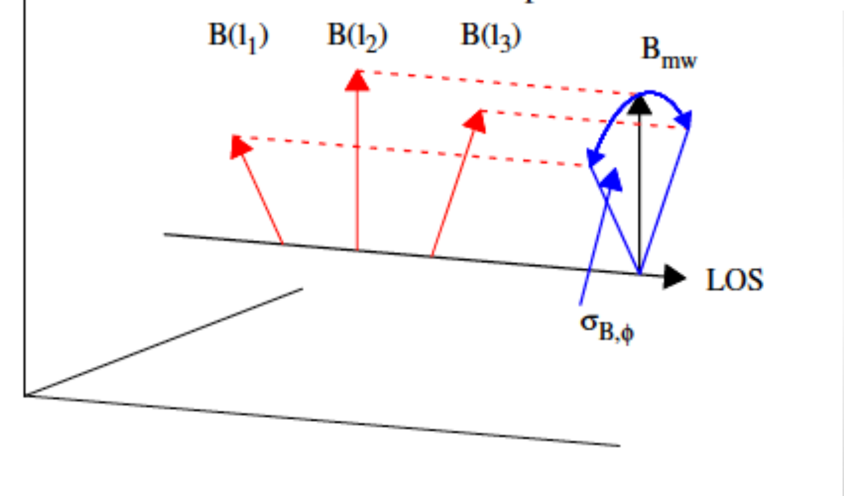


Depolarisation

- Polarisation observations show depolarization
  - Also visible in simulations
- Strongly tangled fields as a source of depolarization?
- Quantify with mean variation along the LOS:

$$\sigma_{B,\varphi} = \frac{\int_{\mathrm{LOS}} \rho \measuredangle(\mathbf{B}(l), \mathbf{B}_{\mathrm{mw}}) \mathrm{d}l}{\int_{\mathrm{LOS}} \rho \, \mathrm{d}l}$$

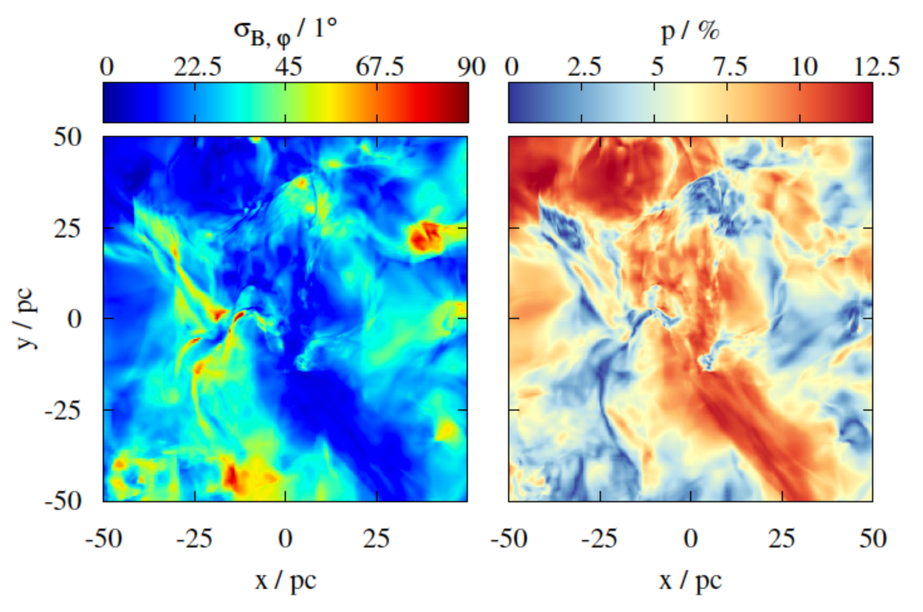


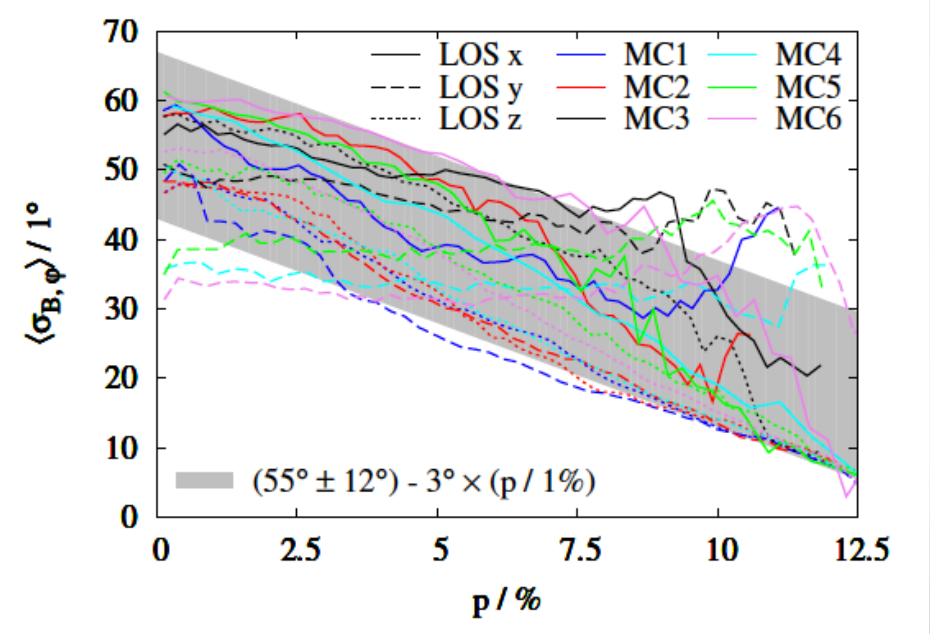


Depolarisation

- Large B-field variation in regions of low polarisation degree
- Strong correlation

$$\langle \sigma_{B,\varphi} \rangle \simeq (55^\circ \pm 12^\circ) - 3^\circ \times \frac{p}{1\%}$$



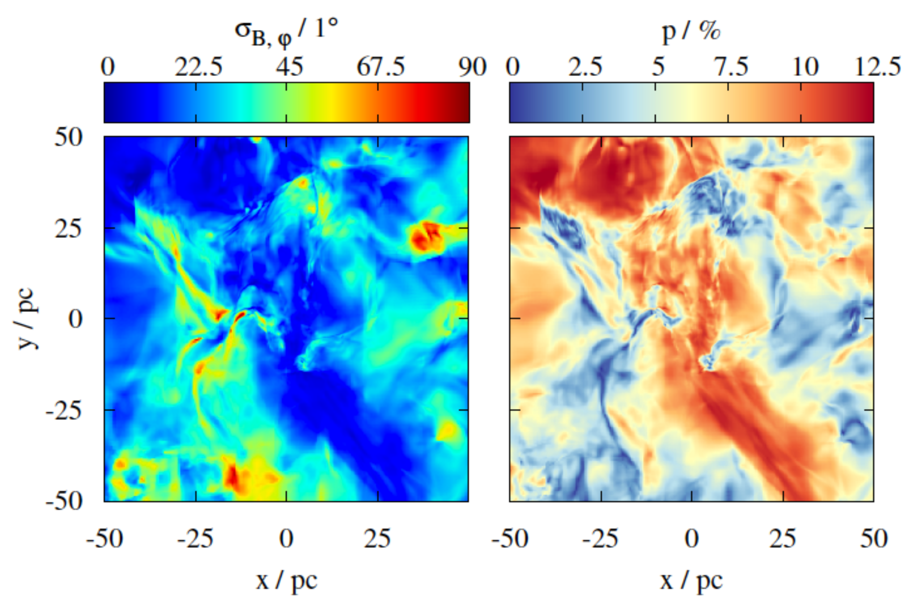


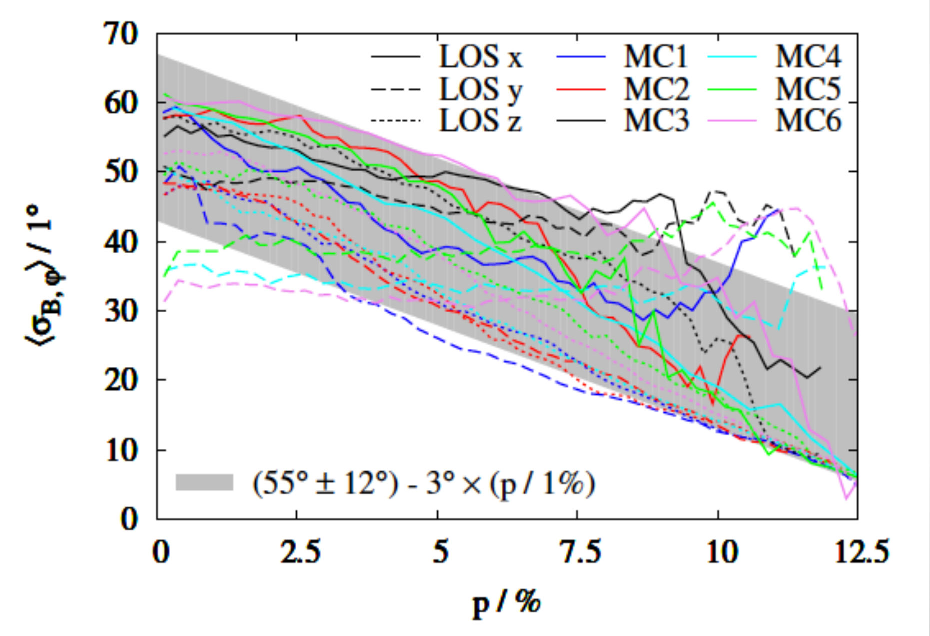
Depolarisation

- Large B-field variation in regions of low polarisation degree
- Strong correlation

$$\langle \sigma_{B,\varphi} \rangle \simeq (55^\circ \pm 12^\circ) - 3^\circ \times \frac{p}{1\%}$$

- Depolarisation on cloud scale caused by tangled B-field
    - … and not misaligned dust
- → Below 2% large variations:
    - Observed field not representation for underlying magnetic field





Summary

- Molecular clouds modelling requires:
    - On-the-fly chemical modeling for H_2 and CO
    - 0.1 pc resolution
- Molecular clouds become inert against external supernova
    - Effect limited in time

- Self-consistent dust polarisation maps including radiative torque alignment with POLARIS
- Dust polarisation traces magnetic field
    - in dense gas
    - with an accuracy of ≤ 5º
- Depolarisation due to strong variation of B-field along LOS
    - dust remains well aligned at $A_V > 3$