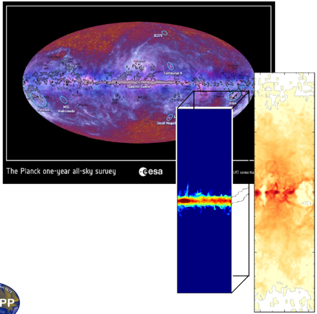
[CII] synthetic emission maps of simulated galactic discs

Annika Franeck
I. Physikalisches Institut, Universität zu Köln
with S.Walch–Gassner, D.Seifried, S.Glover, SILCC–Collaboration



FIR Fine Structure Workshop
June 8$^{\mathrm{th}}$, 2015

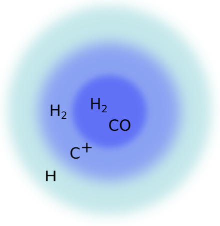
Motivation

[CII] fine–structure emission line from $^2P_{3/2} \rightarrow ^2P_{1/2}$
at $\lambda = 157.74\,\mu$m

- studies of [CII] in the Milky Way:
    - BICE
        - Nakagawa et al. 1995: study of [CII] in different regions in the Milky Way,
    - *Herschel* GOT C+:
        - Pineda, Langer, Velusamy: scale height of [CII] in the Milky Way
        - emission of [CII] from different ISM phases
        - emission of [CII] as a tracer for CO–dark H_2?
- in other galaxies
    - *Herschel* PACS: study of NGC 891 by Hughes et al. 2015

Emission from C^+

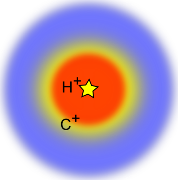
[CII] fine–structure emission line from $^2P_{3/2} \rightarrow {}^2P_{1/2}$ at $\lambda = 157.74\,\mu$m



- no emission from H_2
  no dipole moment
- CO used as tracer

→ C^+ as tracer for CO–dark H_2?

Langer et al. AA 2014
De Looze et al. MNRAS 2011

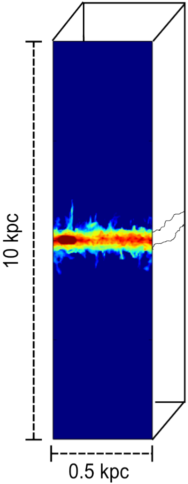


- C^+ from molecular clouds
- C^+ in warm, dense boundary region

→ C^+ as tracer for star formation?

SILCC–Projekt

SILCC = **S**imulating the **L**ife**C**ycle of Molecular **C**louds



- simplyfied chemical network
  - H_2, H, H^+
  - CO, C^+
- initial conditions
  - surface density of the gas Σ
  - supernova rate (SNR)
  - supernova driving

$\Rightarrow$ temperature

$\Rightarrow$ number density of different species

[a] [b]

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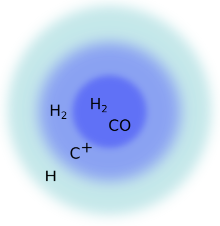
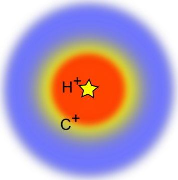
[a] hera.ph1.uni-koeln.de/~silcc/

[b] Walch et al., arXiv 2014

Emission from C^+

[CII] fine–structure emission line from $^2P_{3/2} \rightarrow {}^2P_{1/2}$
at $\lambda = 157.74\,\mu$m





- no emission from H_2

  no dipole moment
- CO used as tracer

→ C^+ as tracer for CO–dark H_2?

- C^+ in PDRs →∼ 50 %

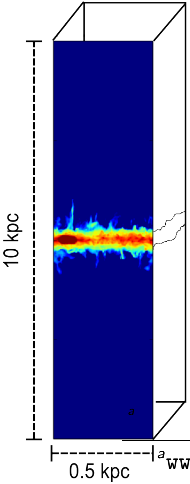
⇒ not included in our simulations

→ C^+ as tracer for star formation?

Langer et al. AA 2014
De Looze et al. MNRAS 2011

SILCC–Projekt

SILCC = **S**imulating the **L**ife**C**ycle of Molecular **C**louds



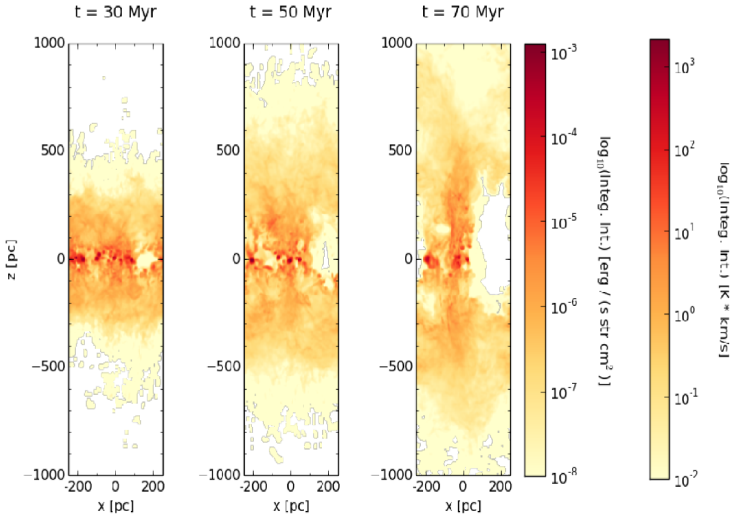
- Radiative transfer simulations with RADMC–3D[a]
- Assumptions:
  - non–Local thermal equilibrium

  ⇒ collisional partners: H_2, H, e^-
    - temperatures
    - number densities
    - collisional rates

[a] www.ita.uni-heidelberg.de/~dullemond/software/radmc-3d/

[CII] Synthetic emission maps

Simulation with initial conditions
similar to those of the solar neighbourhood



[CII] Synthetic emission maps

Simulations with initial conditions
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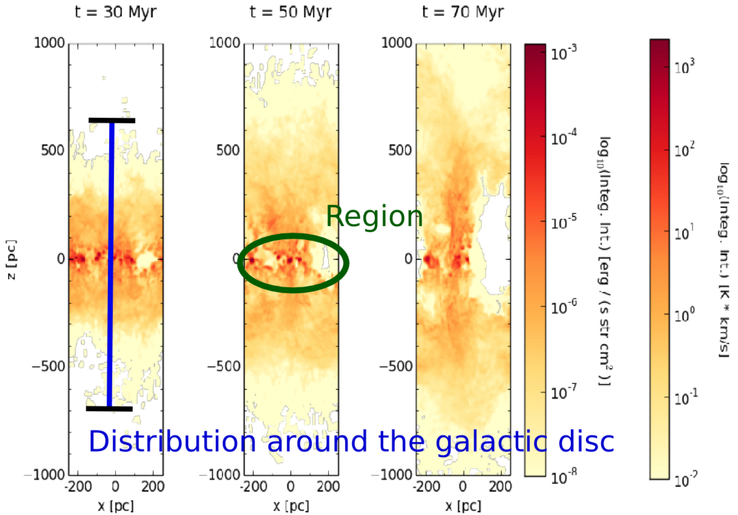
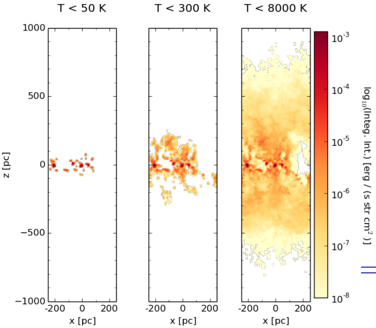
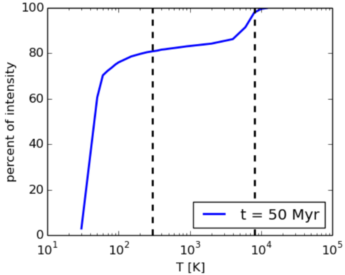


Origin of the emission

t = 50 Myr

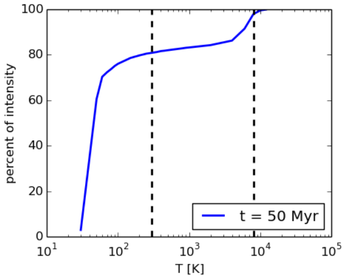


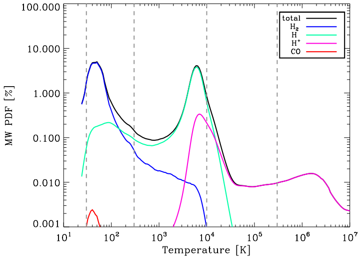


$\Rightarrow$ most emission from cold regions

- T = 0 ... 50 K: $\sim$ 60 %
- T = 50 ... 300 K: $\sim$ 20 %
- T = 300 ... 8000 K : $\sim$ 18 %

Origin of the emission

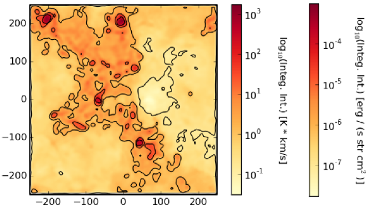


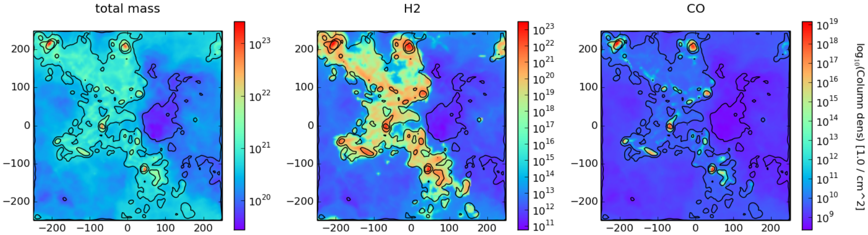


⇒ H_2 main collisional partner in cold regions

Comparison with column density maps

t = 50 Myr

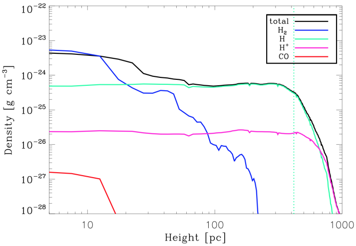




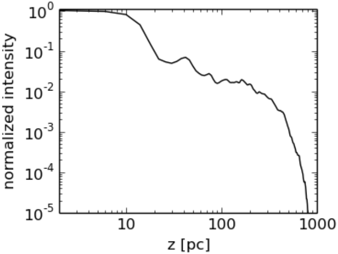
- H_2: column density $> 10^{17}\ /\mathrm{cm}^2 \rightarrow \mathrm{I}([\mathrm{CII}]) > 10^{-6}\ \mathrm{erg}/(\mathrm{s\ str\ cm}^2)$
- CO: column density $> 10^{17}\ /\mathrm{cm}^2 \rightarrow \mathrm{I}([\mathrm{CII}]) > 10^{-5}\ \mathrm{erg}/(\mathrm{s\ str\ cm}^2)$

Density profiles vs [CII] profiles

Density profiles



[CII] intensity profiles



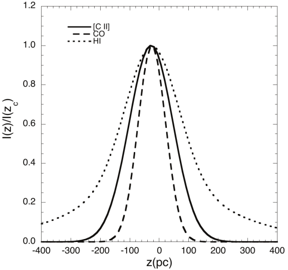
$\Rightarrow$ [CII] profile seems to trace the density distribution

[CII] Scale height in Observations

Distribution of the emission around the disc

⇒ Scale height z_0

$$f(z) = a \cdot e^{-\frac{1}{2}\left(\frac{z-\mathrm{shift}}{z_0}\right)^2}$$



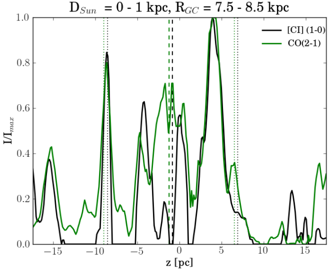
Langer et al., AA 2014, Fig.5

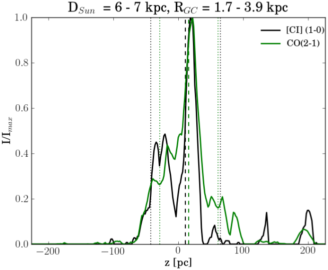
Scale height of ...

⇒ ... the Milky Way: $z_0 = 73\,\mathrm{pc}$ (Langer et al., AA 2014)
⇒ ... NGC 891: $z_0 = 310\,\mathrm{pc}$ (Hughes et al., AA 2015)
(d = 7,2 Mpc)

Scale height in Observations

[CI], CO(2–1) Observations concerning the Galactic radius position



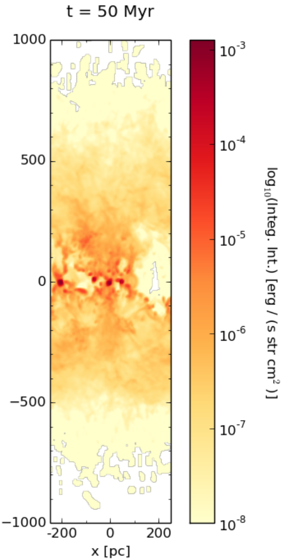


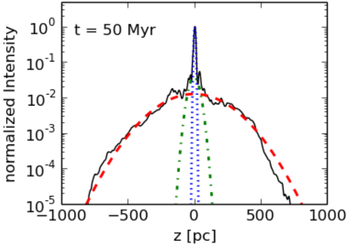
credit: Christian Glück, Universität zu Köln
AST/RO observations

resolution: 1'

$\Rightarrow$ Gaussian distribution on average, not on local scale

Scale height

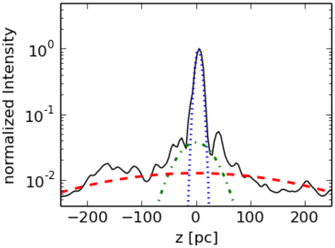


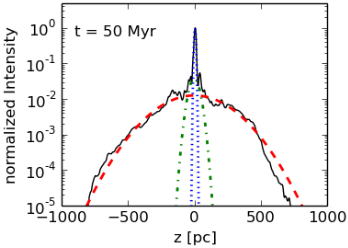


- identify three components:
  - ⇒ fitting each with a Gaussian function
  - ⇒ measure the scale height z_0 of each component

$$f(z) = a \cdot e^{-\frac{1}{2}\left(\frac{z-\mathrm{shift}}{z_0}\right)^2}$$

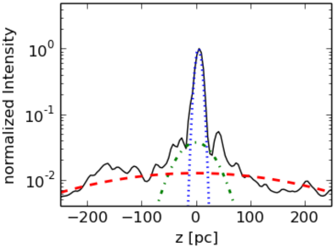
Scale height

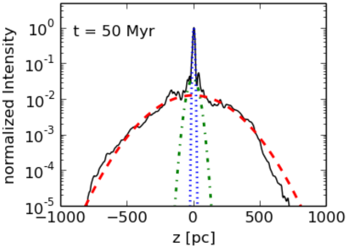




- identify three components — scale height:
  - ⇒ $z_0 = 5.8\,\text{pc}$
  - ⇒ $z_0 = 33.8\,\text{pc}$
  - ⇒ $z_0 = 214.1\,\text{pc}$

Scale height





- Difference to observation:
  - ⇒ warp of the galaxy Burton & te Lintel Hekkert, AAS 1986
  - ⇒ resolution
  - ⇒ averaging over whole galaxy

Summary

- Analysis of [CII] synthetic emission maps...
    - at $\lambda = 157.75\,\mu$m
    - initial conditions of the simulation: solar neighbourhood

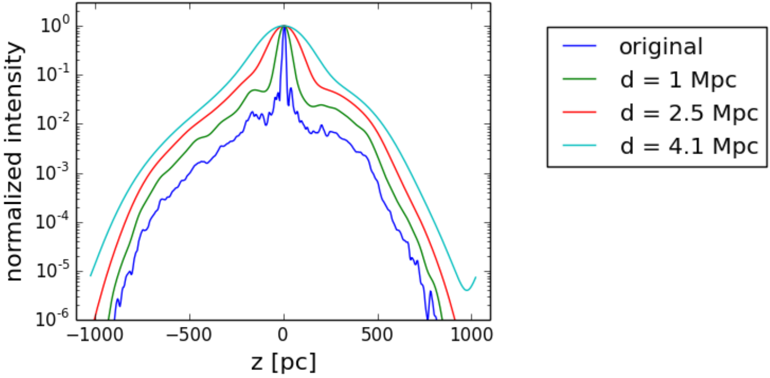
- ... concerning
    - Origin of the emission
        - → mostly from cold, molecular clouds
        - → H_2 most important collisional partner
        - → traces overall distribution of gas
        - work in progress: [CII] as a tracer for CO–dark molecular gas?
    - Scale height
        - → three different components
        - → scale height of expanded component comparable with observations
        - → sharp peaks from molecular clouds
        - work in progress: time evolution

Changing the resolution

- convolving with a Gaussian beam

⇒ Herschel beam: FWHM = 11.5"

⇒ change distances



RADMC–3D — Radiative transfer simulation

Transfer equation

$$\frac{dI_\nu(\zeta)}{ds} = j_\nu(\zeta) - \alpha_\nu(\zeta) I_\nu(\zeta)$$

I: intensity
j_ν: emissivity
α_ν: extinction

ν: frequency
ζ: direction

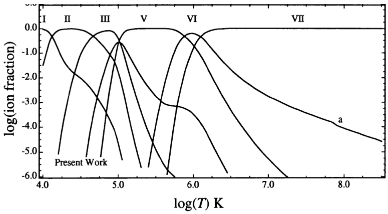
- assuming non–LTE

$\Rightarrow$ collisional partners: H_2, H, e^-

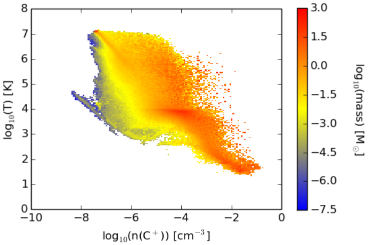
- Input data
  - number densities
  - collisional rates

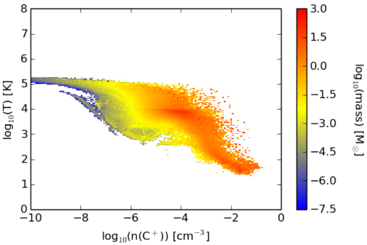
Number density of C^+

- according to Sutherland & Dopita (1993):



→ S010–R0015x01–rand–L5 after 50 Myr:





Collisional partners

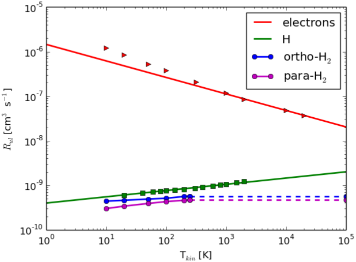
number densities

- $e^- \rightarrow H^+$ and C^+
- H
- $H_2 \rightarrow$ ortho- and para–H_2

$$\frac{n(\mathrm{ortho–H_2})}{n(\mathrm{para–H_2})} = 9 \cdot e^{-171\,\mathrm{K}/T_{rot}}$$

(Rachford et al. ApJS, 2009)

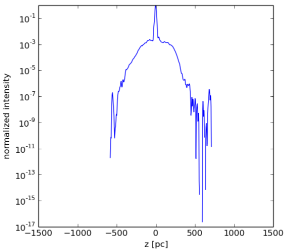
collisional rates



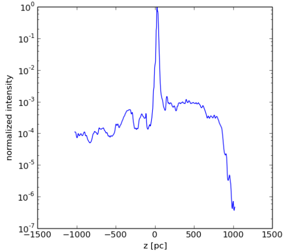
- data points from Leiden database
- fits from Goldsmith et al. ApJS, 2012

Different initial conditions

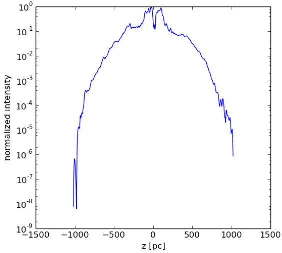
lower SN rate



clustered SN positions



without self–gravity



with magnetic field and clustered SN positions