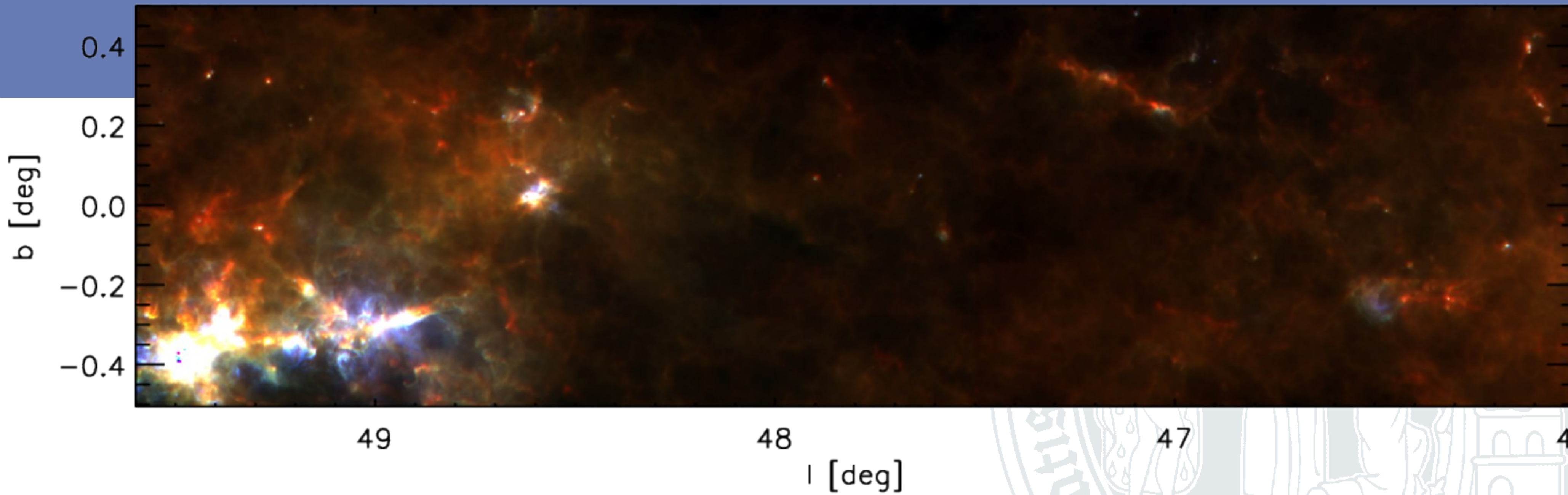
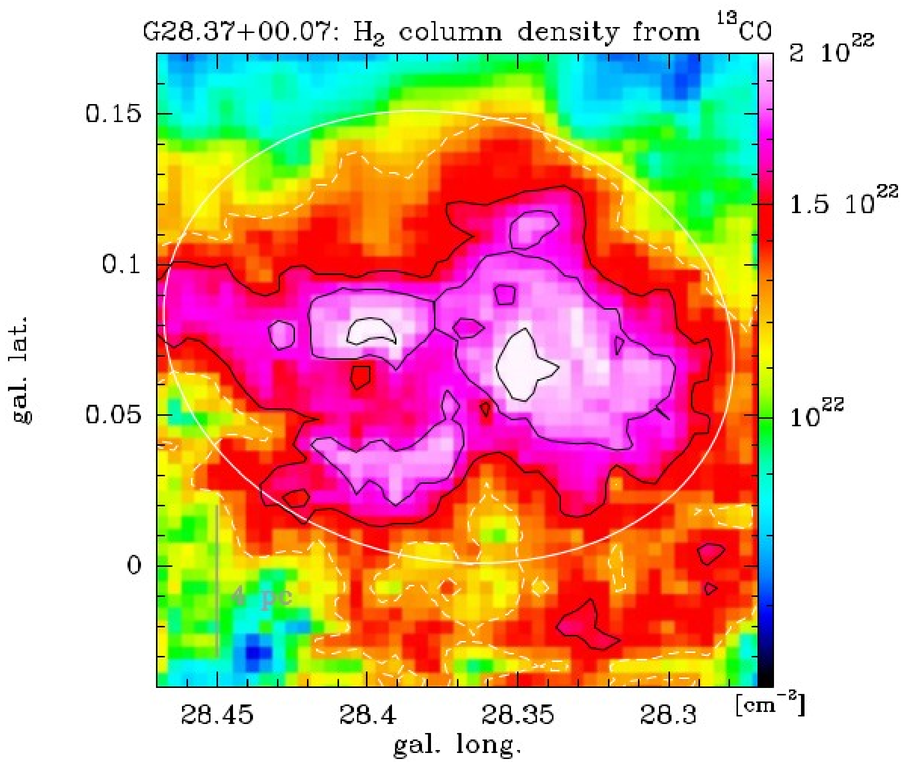


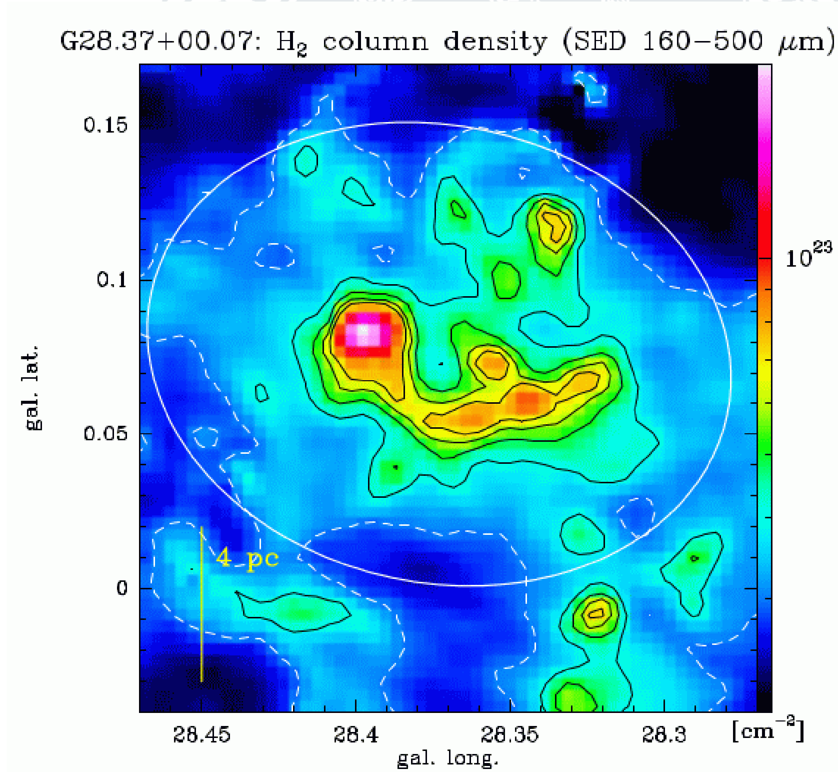
Be careful with observational data

Volker Ossenkopf-Okada

KOSMA
(Kölner Observatorium für SubMm Astronomie),
I. Physikalisches Institut, Universität zu Köln

- **What is the column density of an interstellar cloud?**





Schneider et al. (2015)

- What to observe to trace the column density?
- What is the “boundary” of a cloud?

Def.: synonymous here $N_{\mathrm{H}} = N(\mathrm{H} + 2\mathrm{H}_2) = 1.9 \times 10^{21}\mathrm{cm}^{-2} \equiv A_{\mathrm{V}} = 1.0$

Column densities

Masses, turbulent structure, gravitational stability:

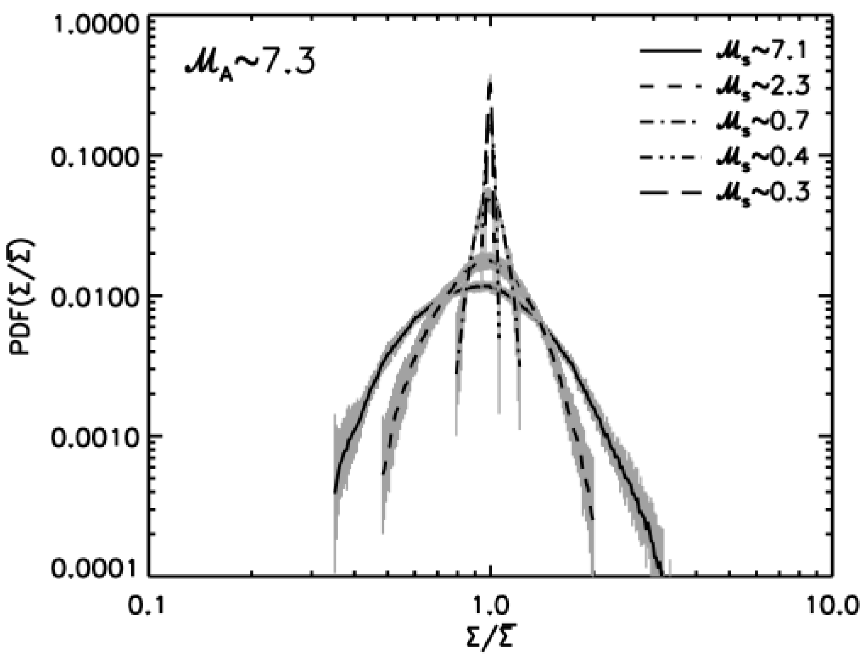
- Turbulent clouds:
  - Log-normal PDFs:

$$p_\eta(\eta) = \frac{1}{\sqrt{2\pi}\sigma_\eta} \exp\left(-\frac{\eta^2}{2\sigma_\eta^2}\right)$$

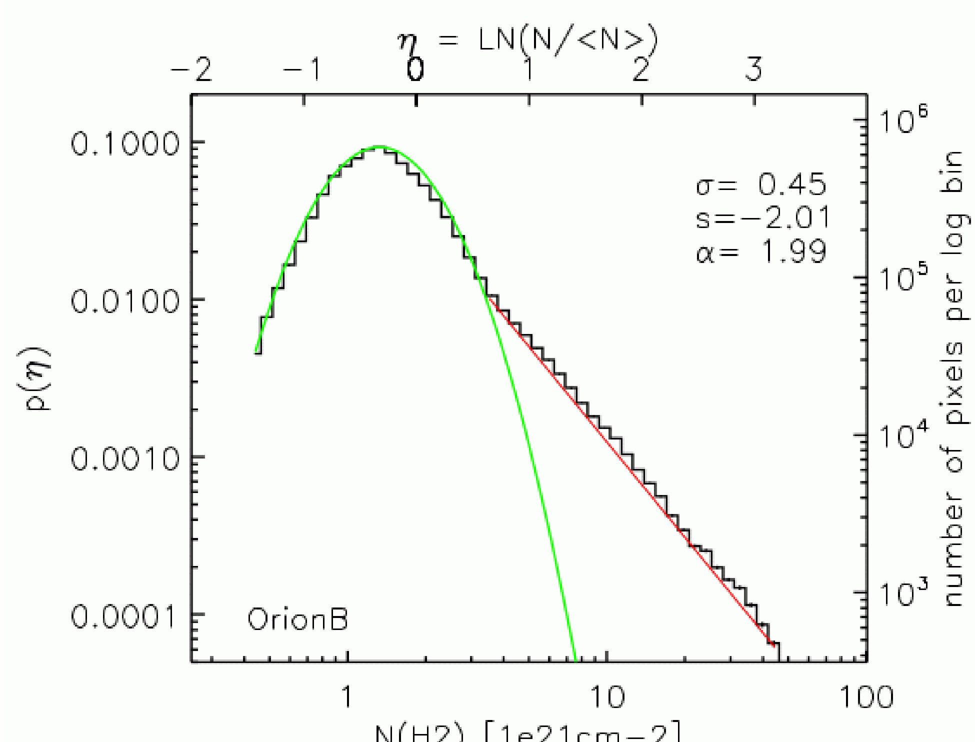
$$\eta = \ln\left(\frac{N}{N_{\rm peak}}\right)$$

- Gravity:
  - Run-away density growth:
    → Power-law tail:

$$p_\eta(\eta) = \left(\frac{N}{N_{\rm peak}}\right)^{-s}$$



Column-density PDFs from isothermal simulations with different sonic Mach numbers (Kowal et al. 2007)

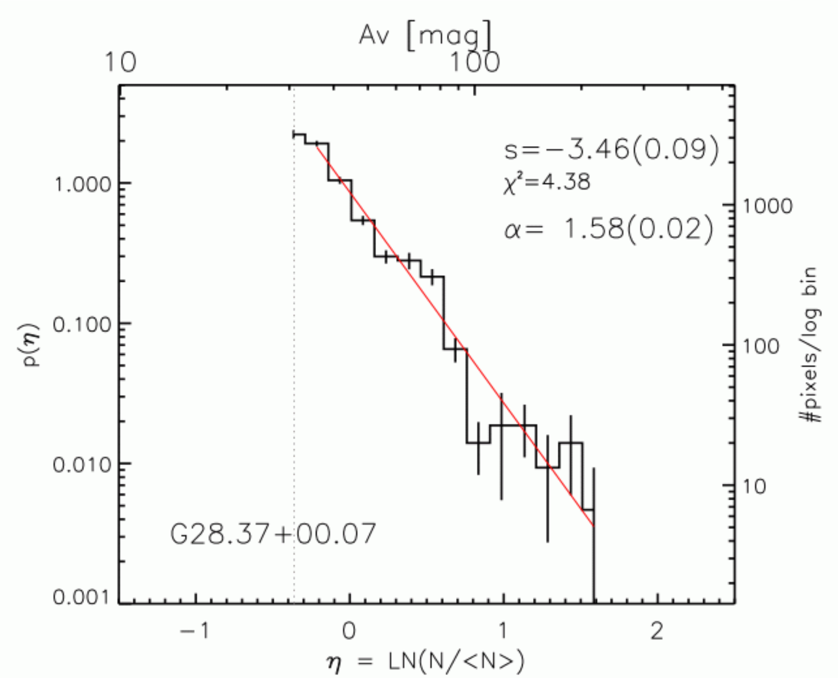


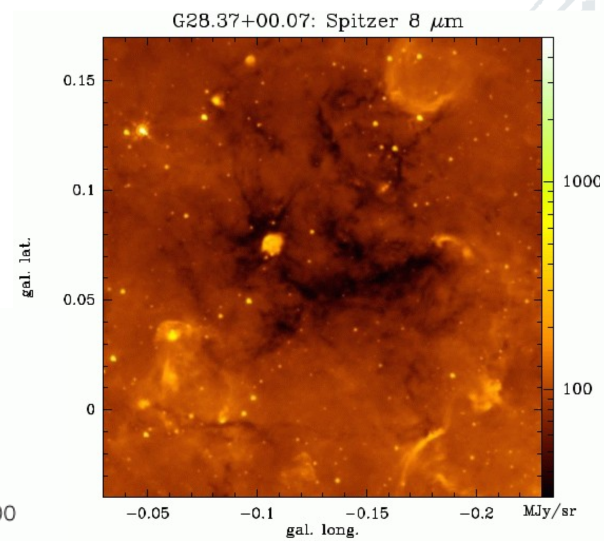
Schneider et al. (2013): PDF in Orion B

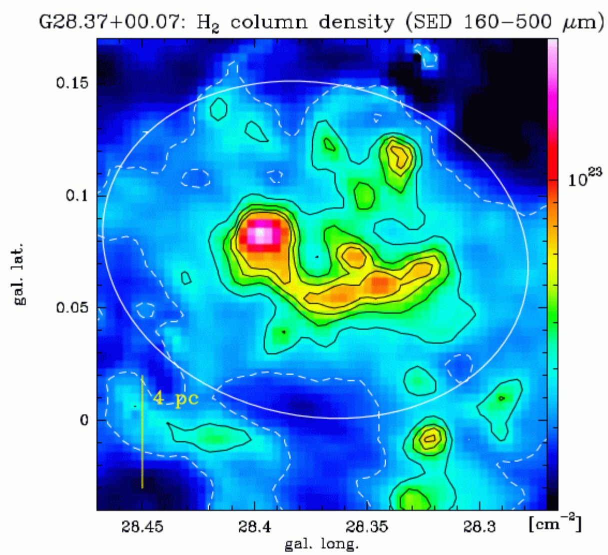
Example

IRDC G28.37+0.07:

- Analysis of extinction data and Herschel column density maps:

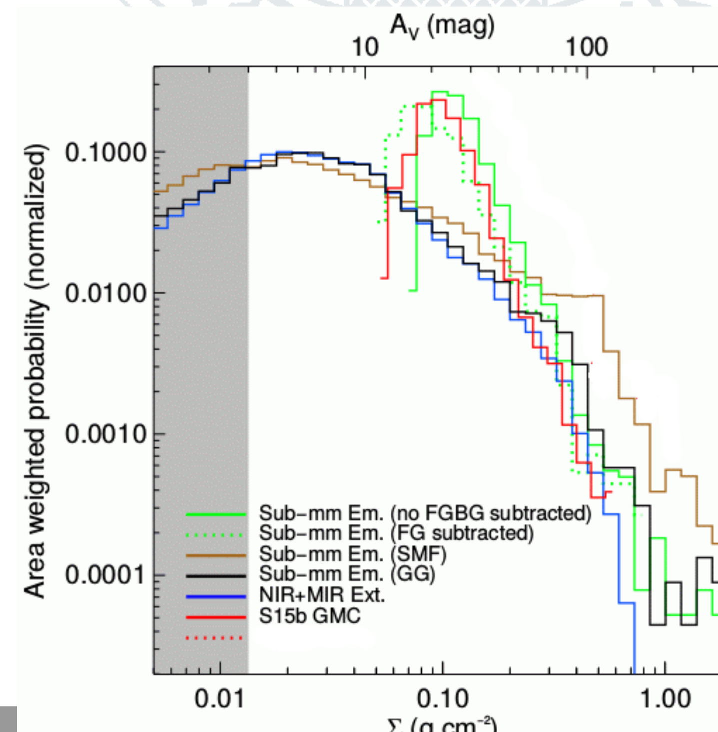






IRAC 8µm

Herschel column density



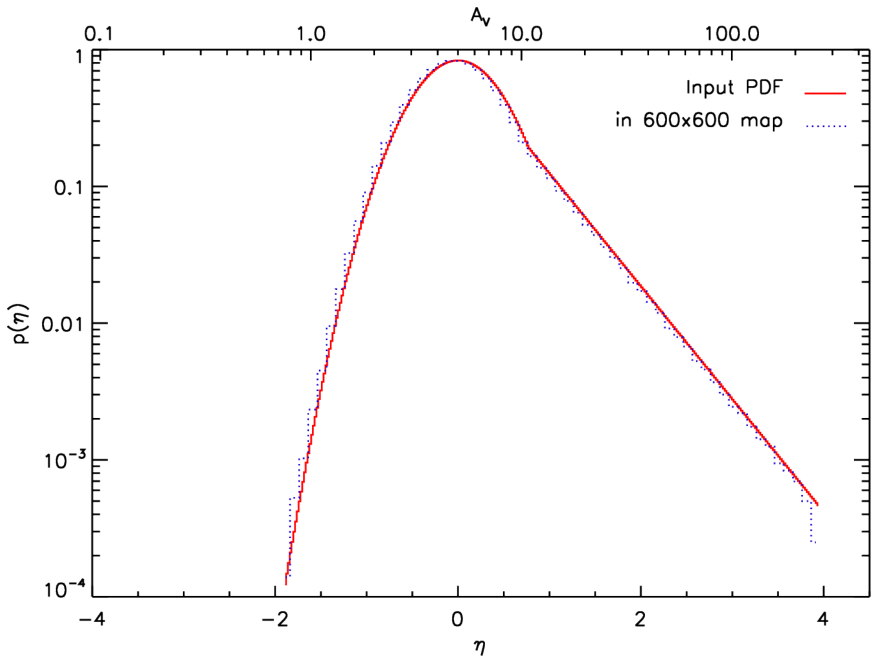
- Schneider et al. (2015): **only power law tail**
- Kainulainen & Tan (2013), Lim et al. (2016): **purely log-normal**
  - **For same region!**

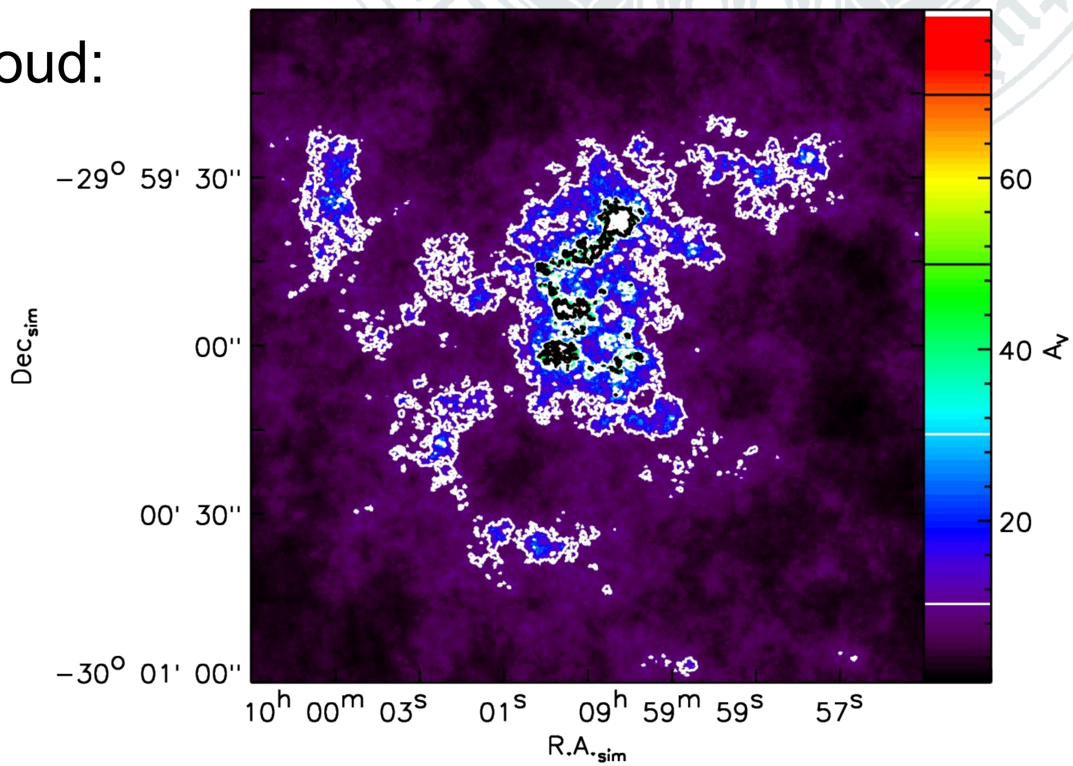
Possible problems in observations and data handling

- Finite spatial resolution
- Finite map size
- Noise
- Interferometric observations
- Line-of-sight contamination

Ossenkopf et al. (2016)

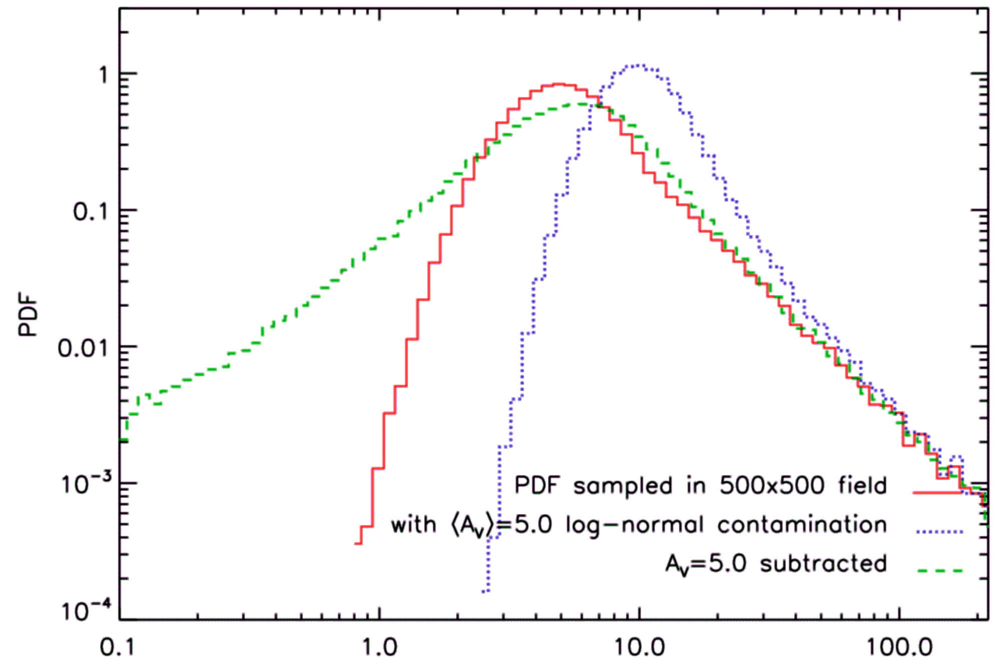
- Simulation of all effects for test cloud:

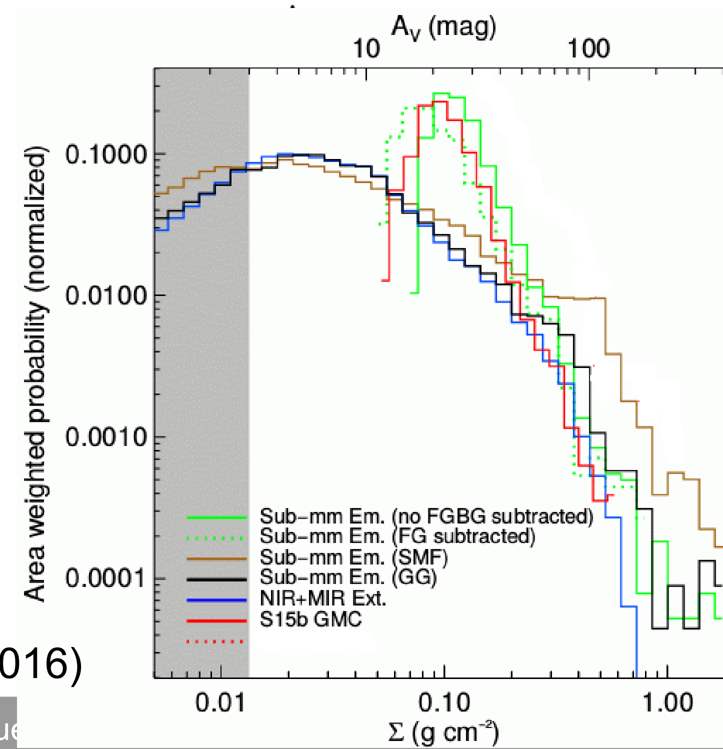




Main problem

- Line-of-sight contamination
  - Contamination does not create separate peak
  - Lognormal part "compressed"
  - Power-law tail is steepened
  - Original parameters can be recovered if contamination is known
  - Reasonable correction already by constant screen subtraction
  - **Critical input:** known contamination
    - What material is part of the cloud?
    - What is behind the cloud, what is in front of it?

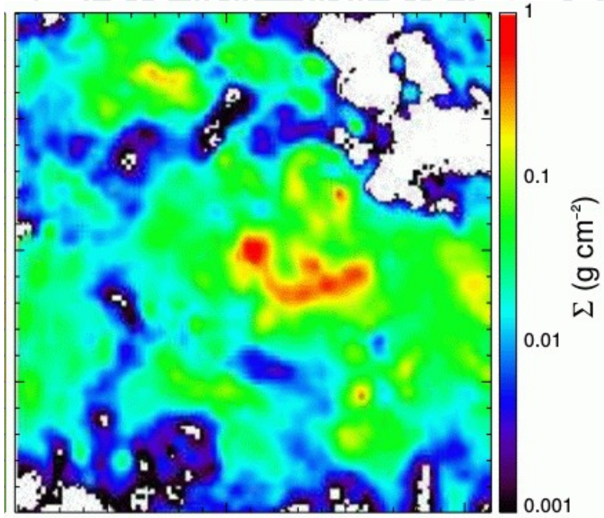




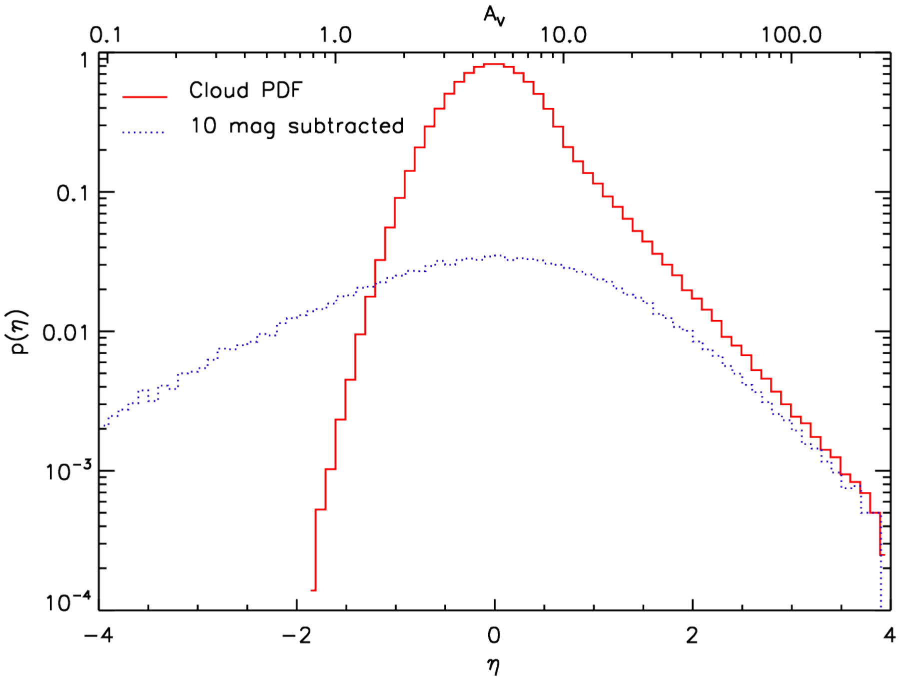
Effect of contamination subtraction for G28.37 (Lim et al. (2016)

Application of LOS correction

- Lim et al. (2016):
  - Contamination correction for G28.37
  - Assumes average Galactic column density profile
    - High contamination: $A_V > 30$
    - Possibly over-correction
      - Creates negative areas
  - Simulation of "over-correction":



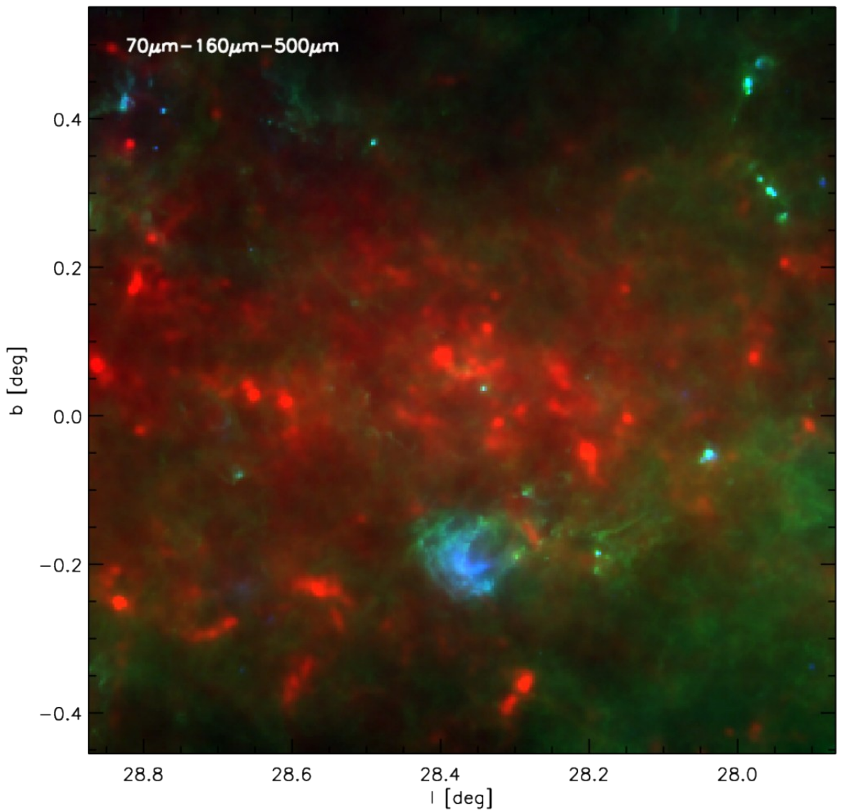
Contamination subtracted map



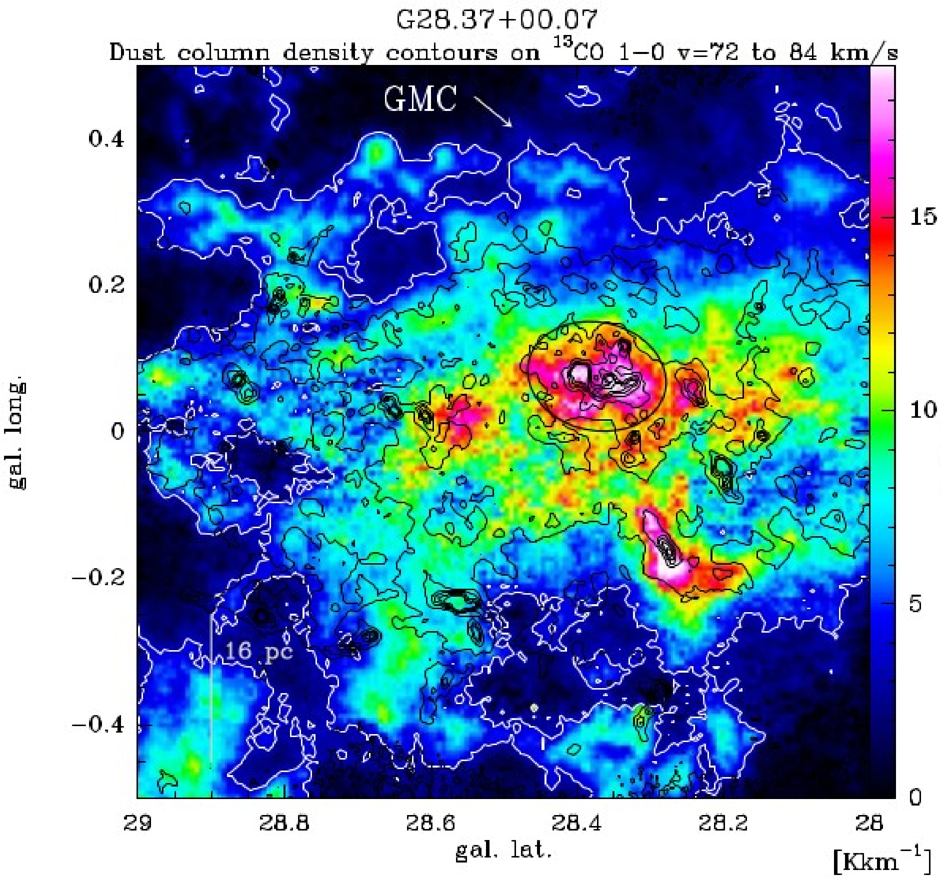
- Over-correction creates PDF that seems log-normal, but has power-law tail
- Schneider (2013) analysis assumed only $A_V \approx 7$ contamination
- **What is the true LOS contamination?**

LOS confusion

- Large-scale spatial distribution
  - Dust emission shows little extended material, but many individual features



Hi-GAL image of dust emission in G28 region



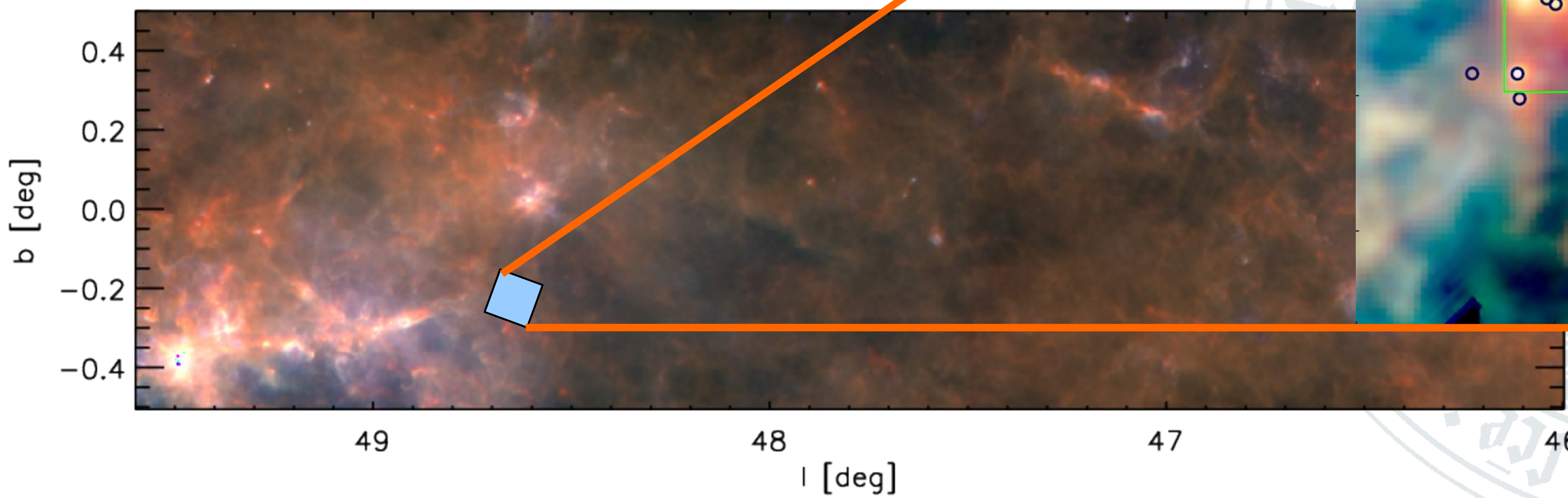
^{13}CO 1-0 intensities with dust contours

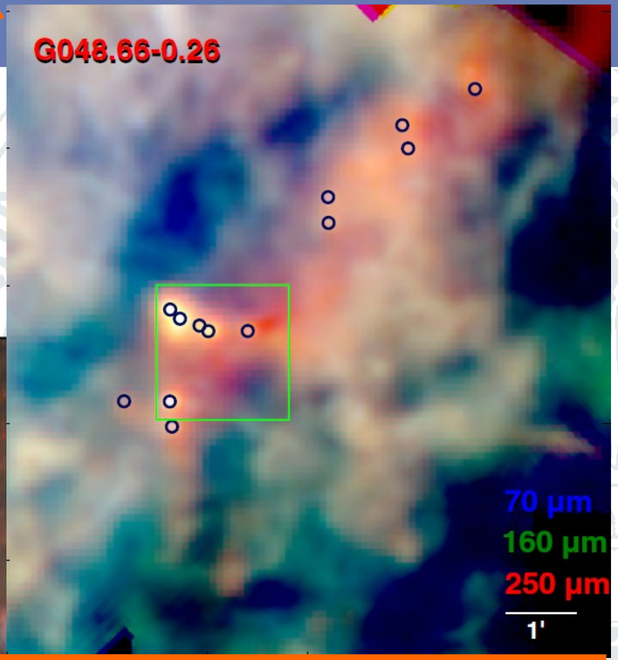
  - Distinction needs separation along the line of sight
    - Only possible when using velocity information from atomic or molecular lines

Resolve contamination from line profiles

Example 2: IRDC G48.66

– Observation in molecular lines, [CI], [CII]

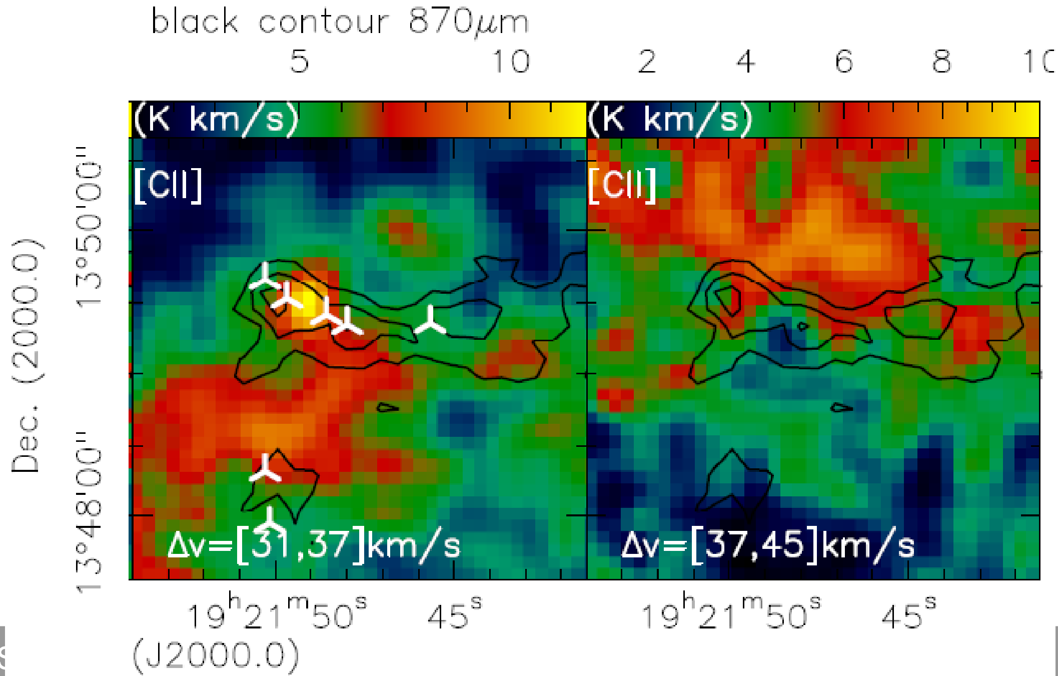




Pitann et al. (2013)

Hi-GAL image of G48 region

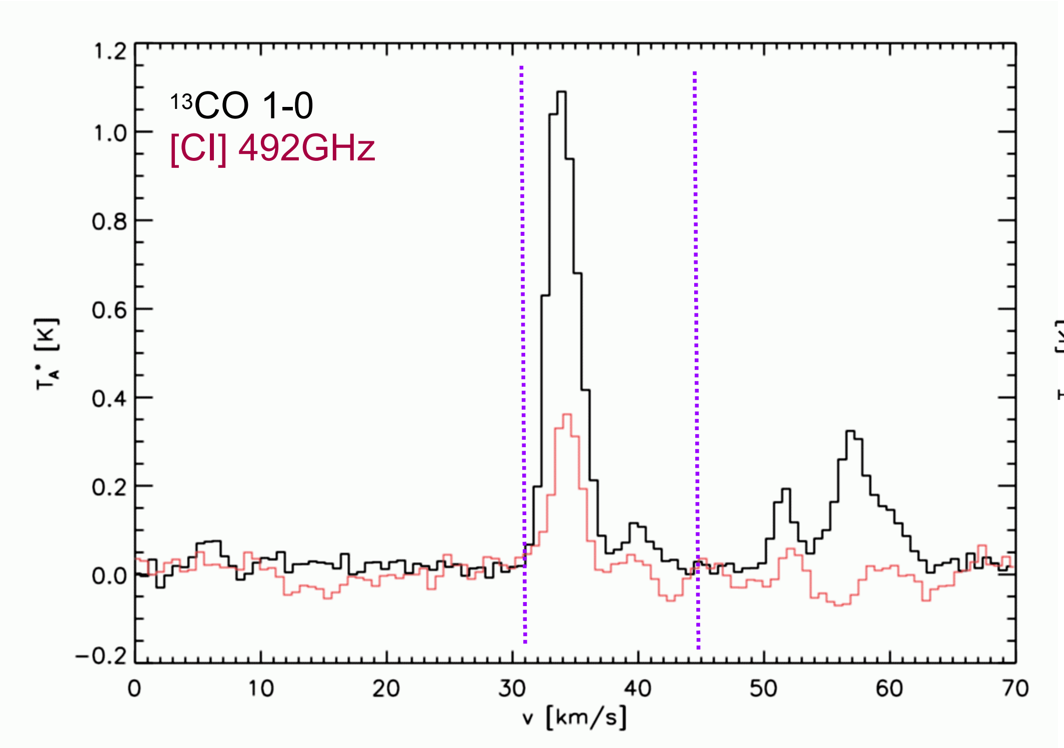
– Velocity gradient in [CII] map interpreted as possible colliding flow

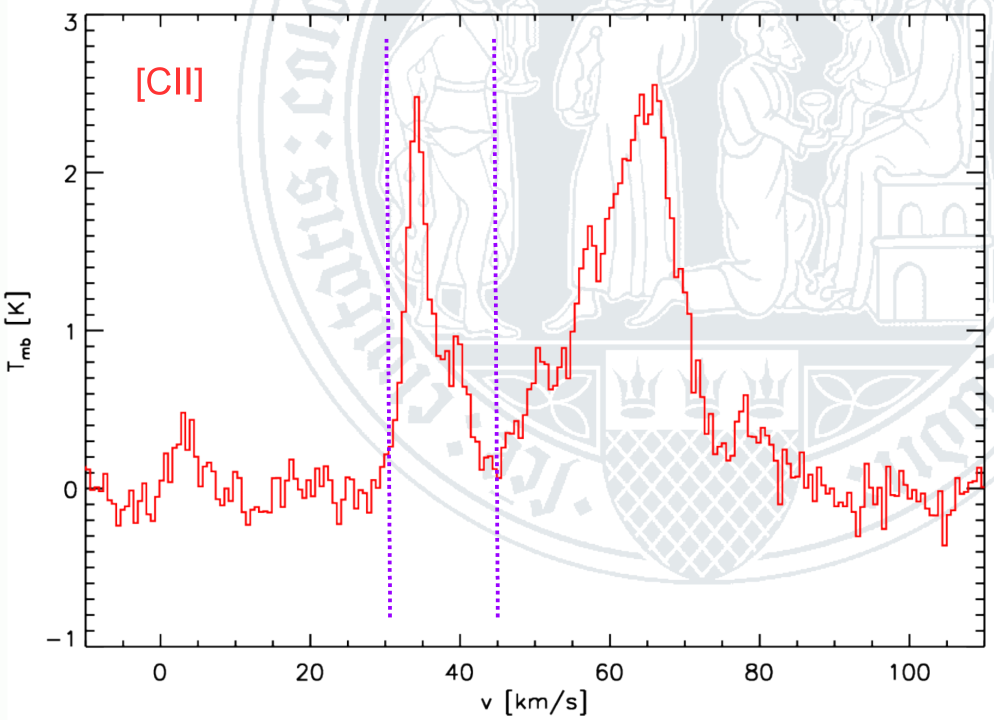


Beuther et al. (2014)

Contamination and line profiles

Line profiles in molecular lines, [CI] and [CII]



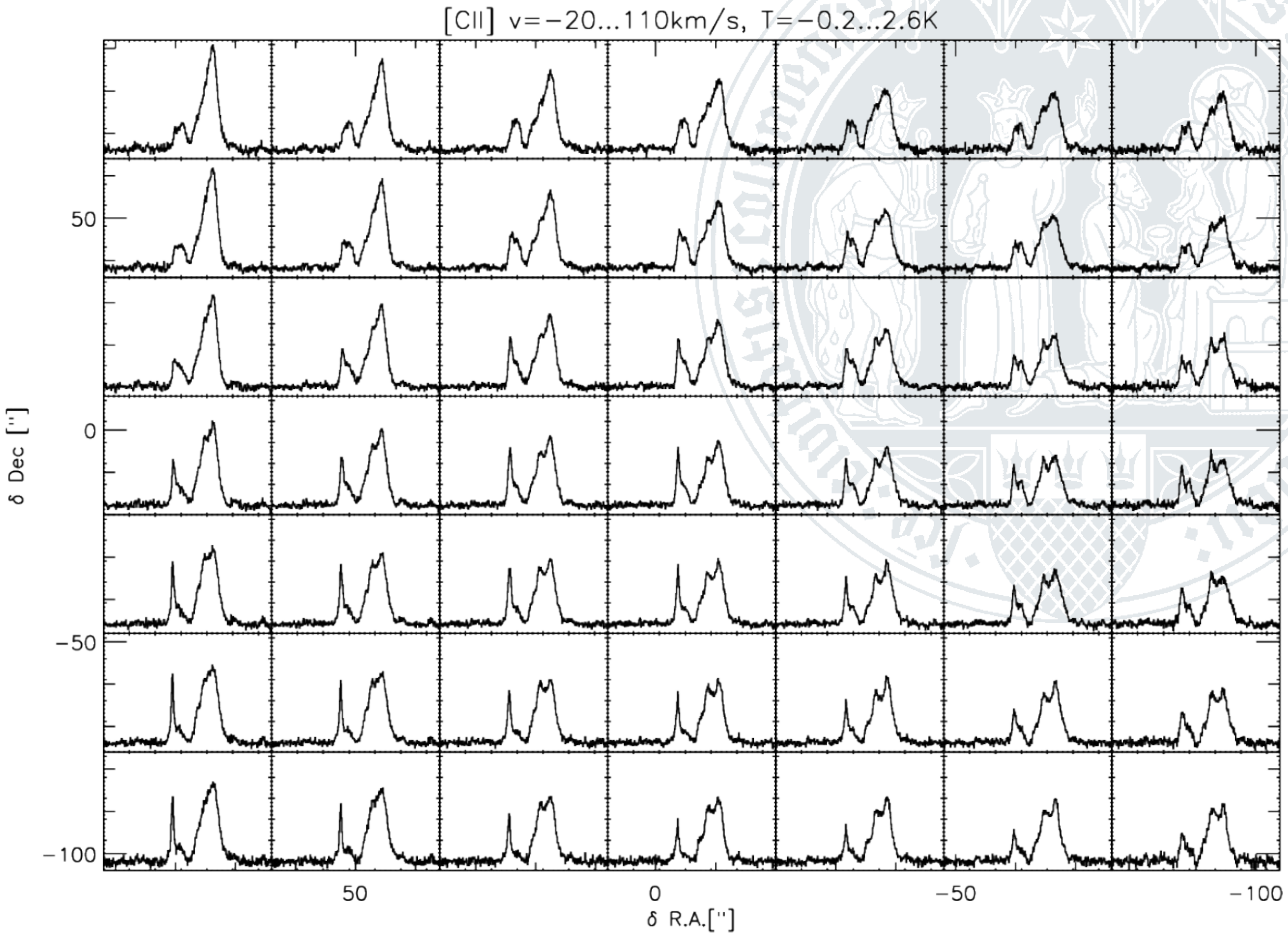


Comparison of line profiles going beyond the velocity range analysed in Beuther et al. (2014)

- IRDC G48.66 velocity component only minor contribution in total column!

Contamination and line profiles

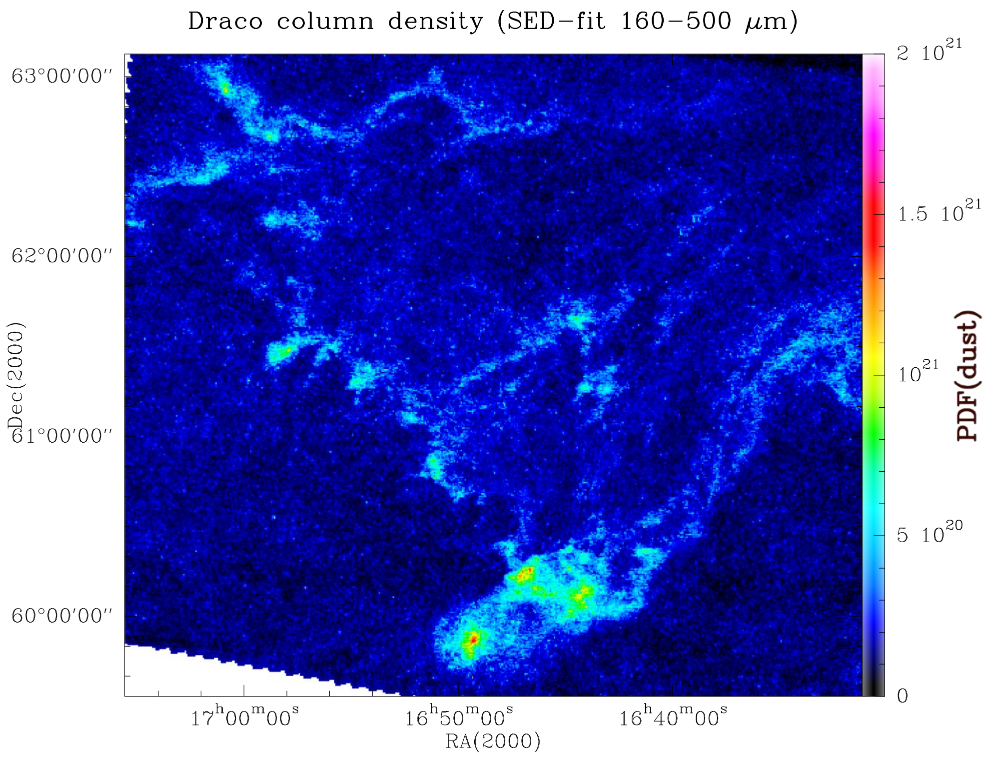
A wider view



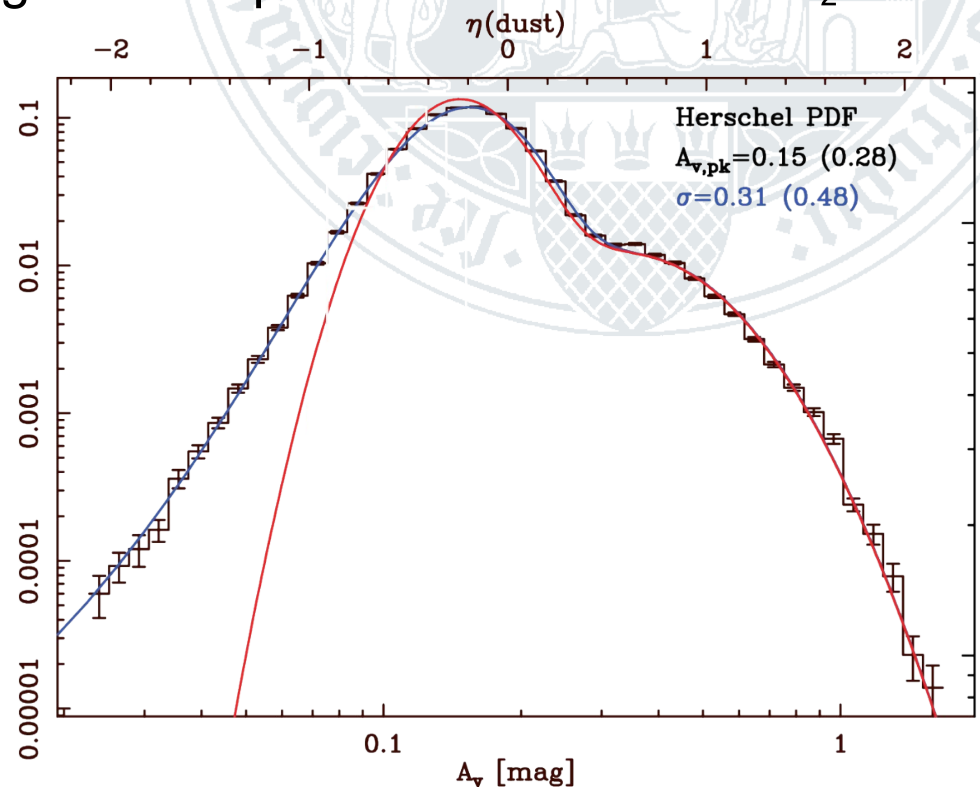
- Contamination correction requires detailed chemical analysis of all velocity components

Observation: Draco

- No confusion within the Galactic plane
- Column density from SED fit to Herschel SPIRE (250µm-500µm) and PACS (160µm) maps
- Two peaks, separation at $A_V \approx 0.3$ → assignment to phase transition HI → H_2



Total column density

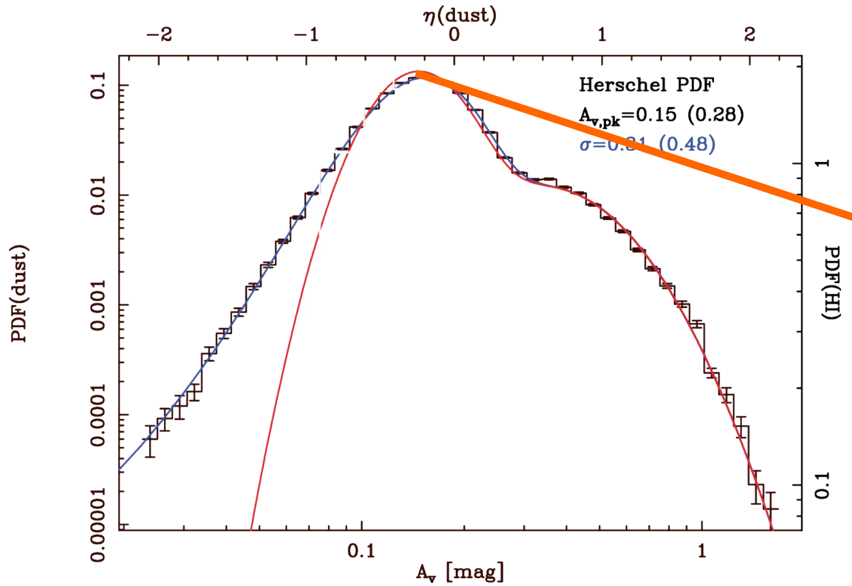


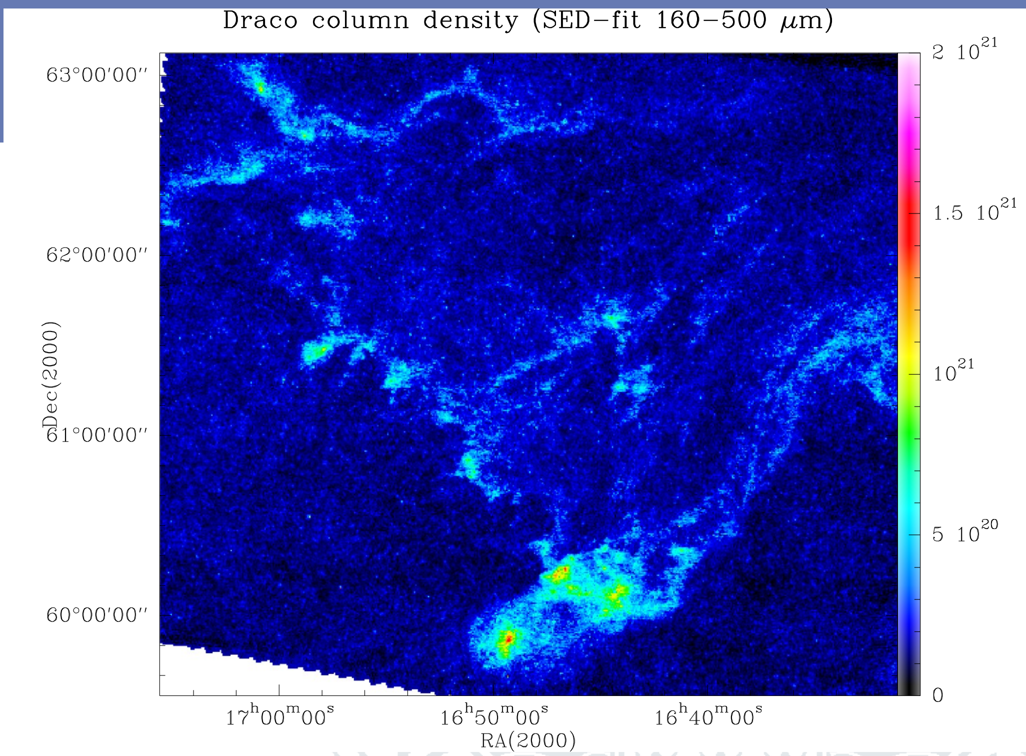
Column-density PDF (Schneider et al. subm.)

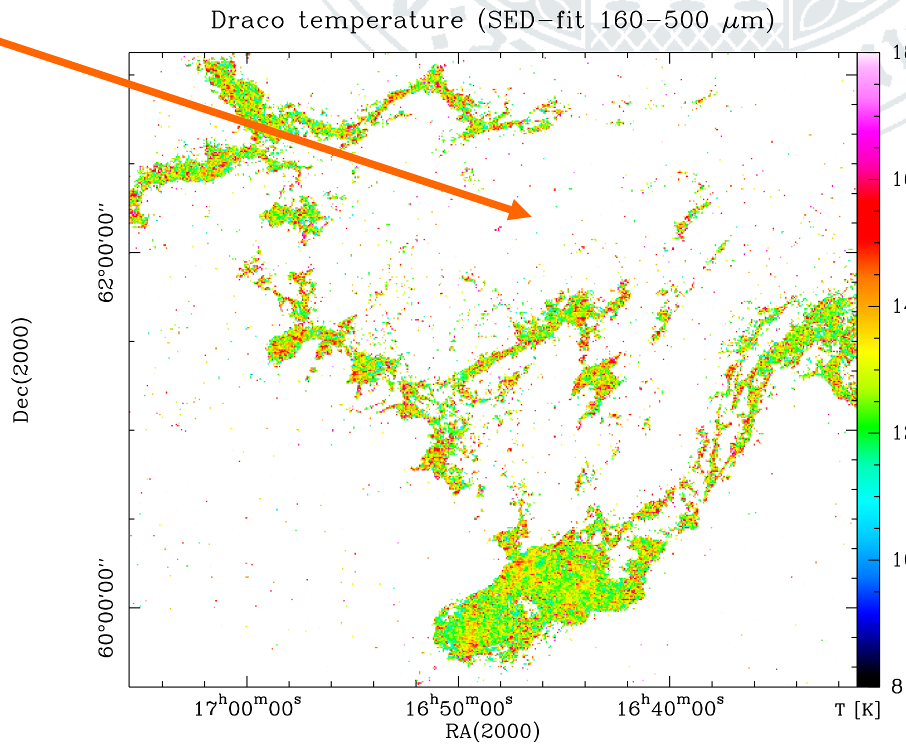
Some closer look

Draco column density

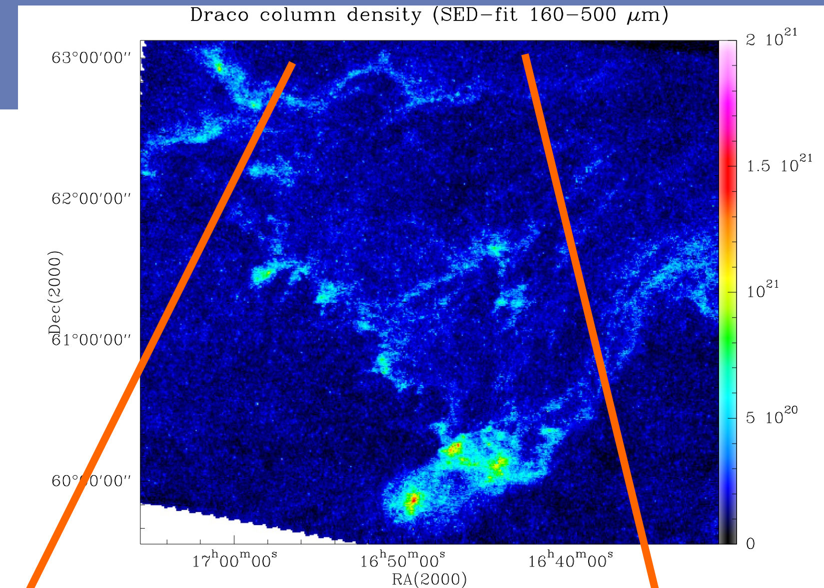
- Low column density peak stems from low-flux regions without reliable temperature determination





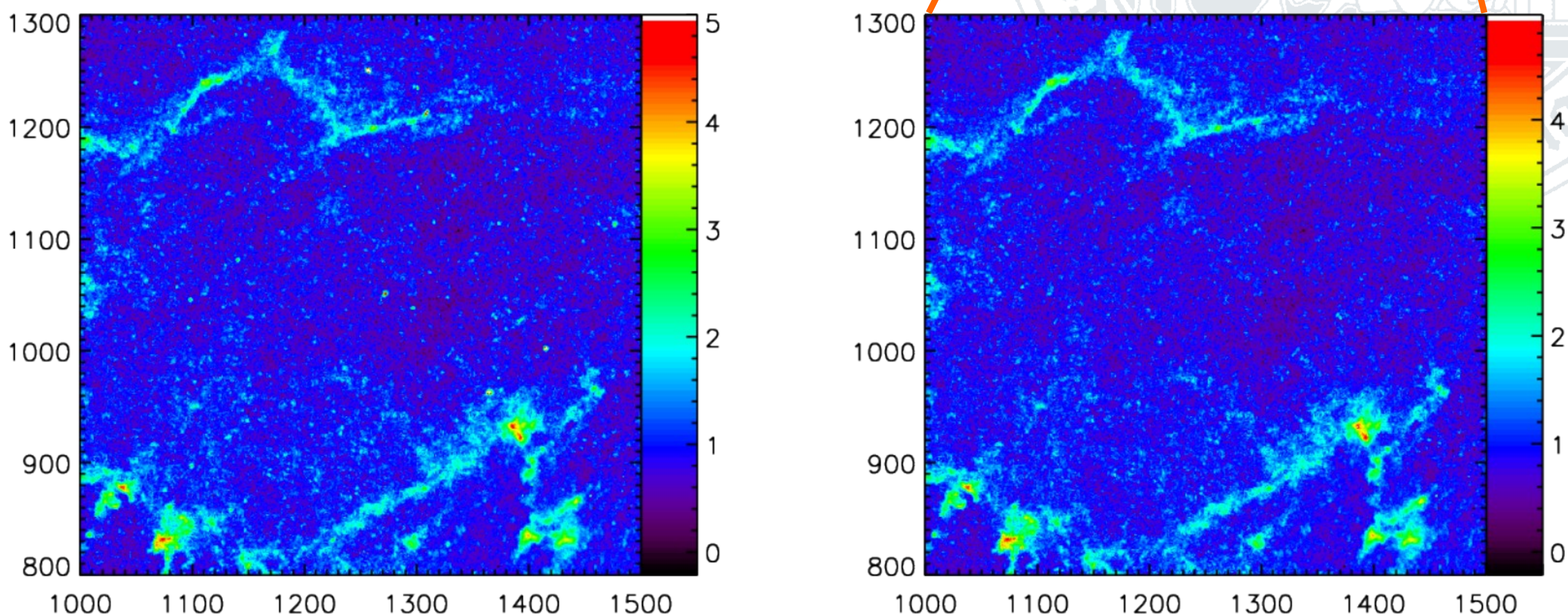


- **What do we really see there?**



Emission from “empty” regions

- Contamination by galaxies
  - Partially resolved
    - Resolved galaxies easy to remove
  - **Cosmic Infrared Background** (CIB)



Zoom in the 500μm SPIRE map before and after removal of resolved galaxies

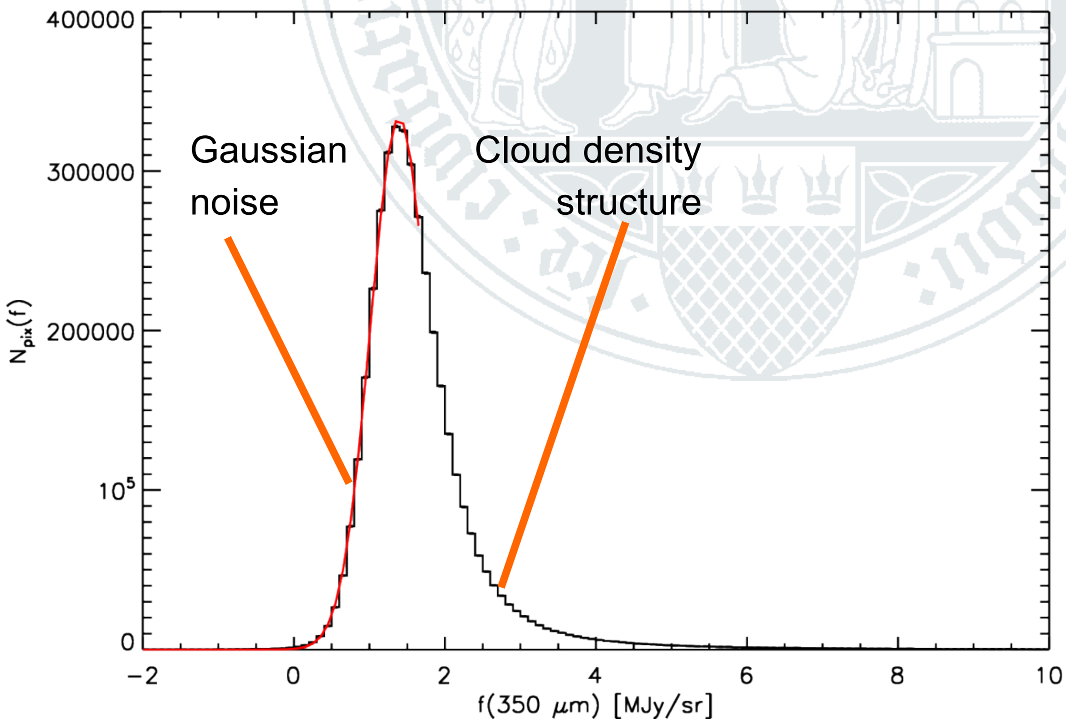
Measure emission from “empty” regions

Zero-level in the maps

- Implemented in HIPE
  - large-scale corrections, from Planck data
- Determine from noise-dominated intensity distribution
  - Linear PDF

- **Result:**
  - 250µm: 1.7 MJy/sr
    - CIB subtracted: 0.9 MJy/sr
  - 350µm: 1.4 MJy/sr
    - CIB subtracted: 0.7 MJy/sr
  - 500µm: 0.7 MJy/sr
    - CIB subtracted: 0.3 MJy/sr

(CIB provides half of the emission.)



Linear PDF of the intensities at 350µm. The peak is governed by the large “empty” regions.

Emission from “empty” regions

Corresponding column density

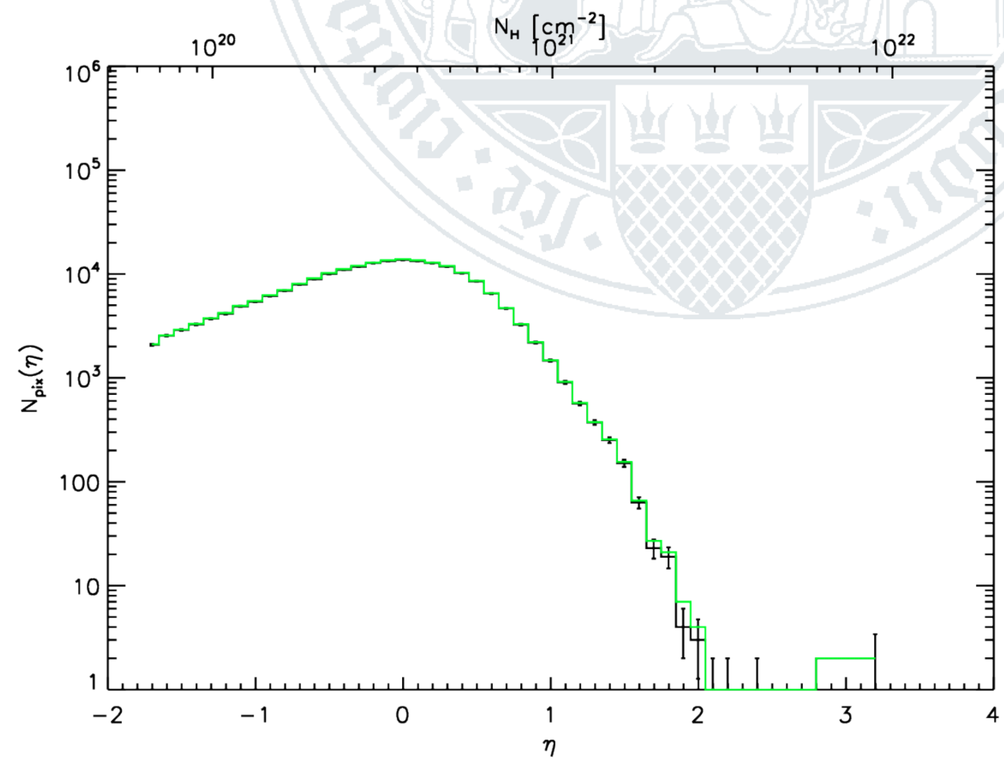
- SED fit to zero level after CIB subtraction:

$$\beta = 2.0 \rightarrow T = 12.1 \text{ K}, N_H = 2.0 \times 10^{20} \text{cm}^{-2} \cong A_V = 0.1$$

$$\beta = 1.8 \rightarrow T = 12.8 \text{ K}, N_H = 1.6 \times 10^{20} \text{cm}^{-2} \cong A_V = 0.08$$

- Resulting new PDF
  - No double peak any more!
  - Column densities below $3\ 10^{20}$ cm^{-2}, i.e. $A_V = 0.15$ very questionable!

- Origin of zero-level emission?
  - **Unclear**

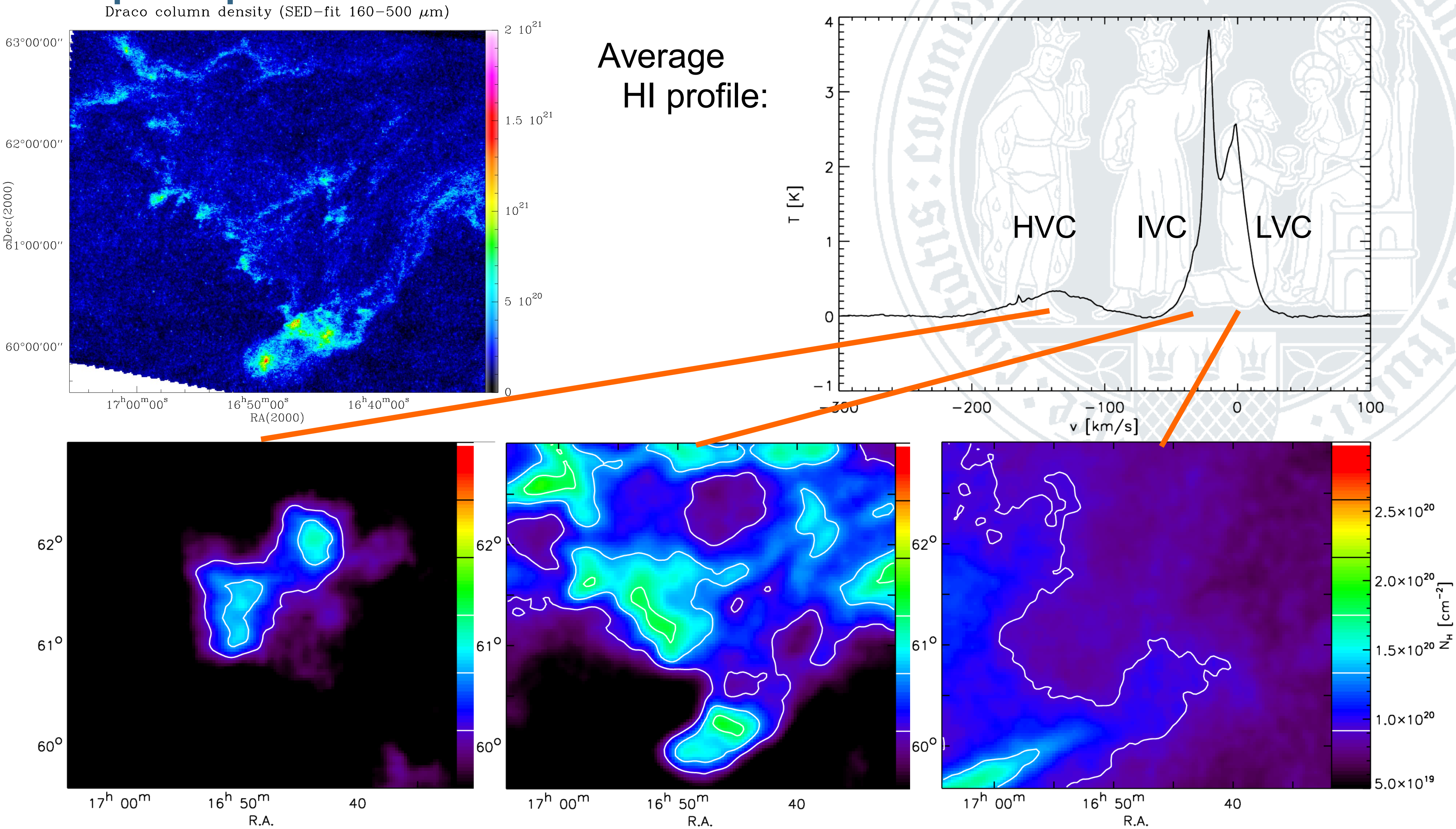


Draco column-density PDF before/after bright galaxy subtraction.

Contamination correction from line profiles?

Compare spatial distribution with HI and CO

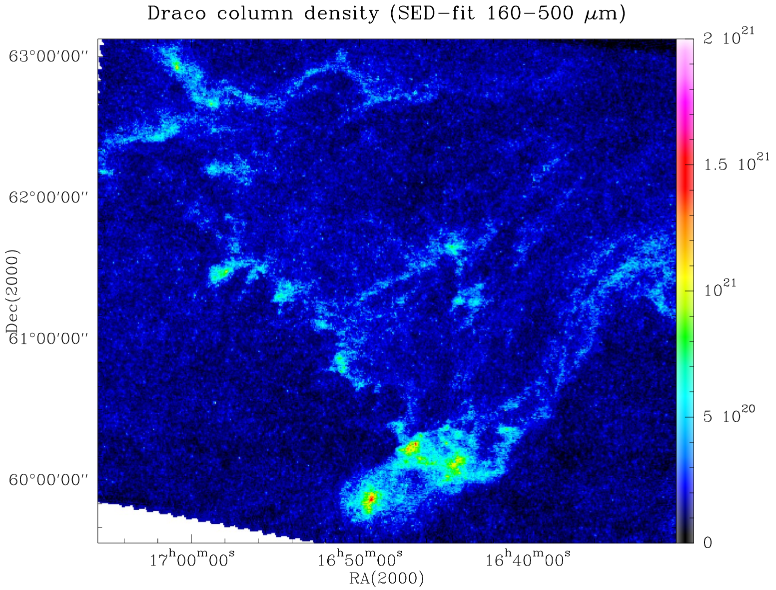
Average HI profile:



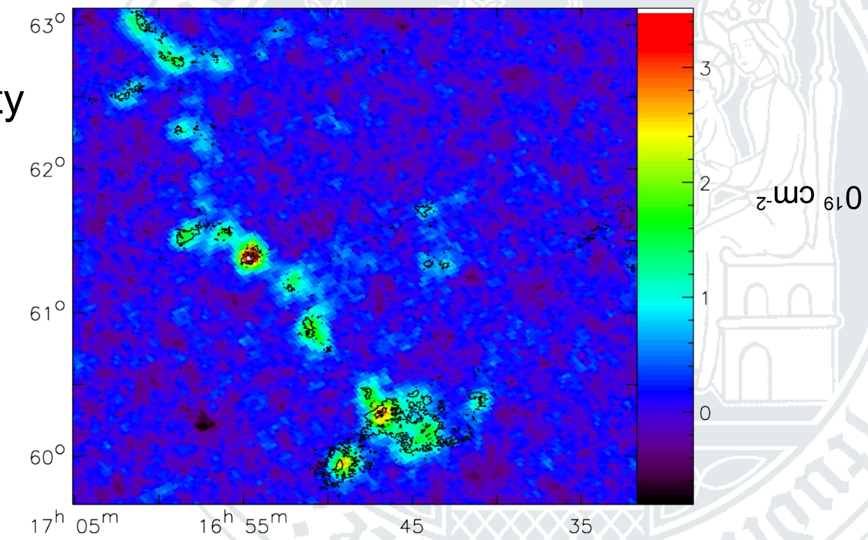
- Only IVC velocity component shows up in dust: **Dust-to gas ratio not constant!**

Contamination correction from line profiles?

Compare spatial distribution with HI and CO



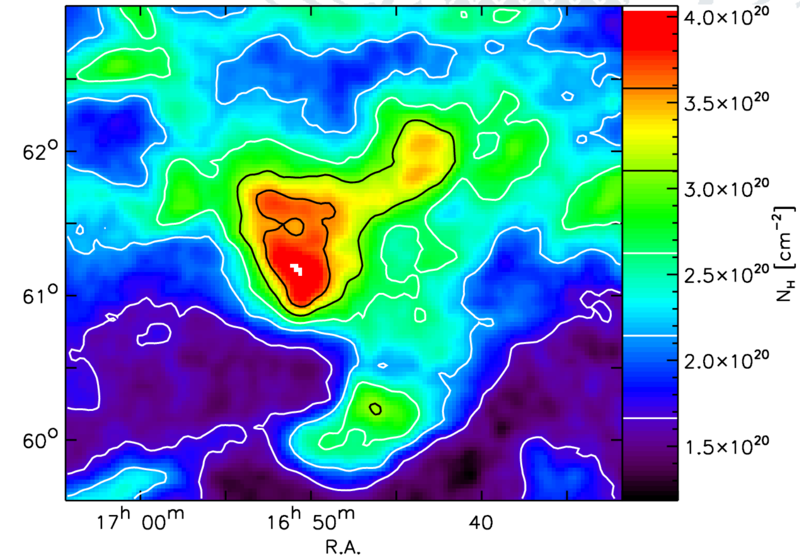
CO-based column density (with dust contours)



- Molecular gas (CO) well correlated with dust column density, but total column low.
- Total HI distribution very different
  - Not consistent with extended zero offset

→ **Every tracers sees a somewhat different column density!**

  - Even dust does not trace the full column density

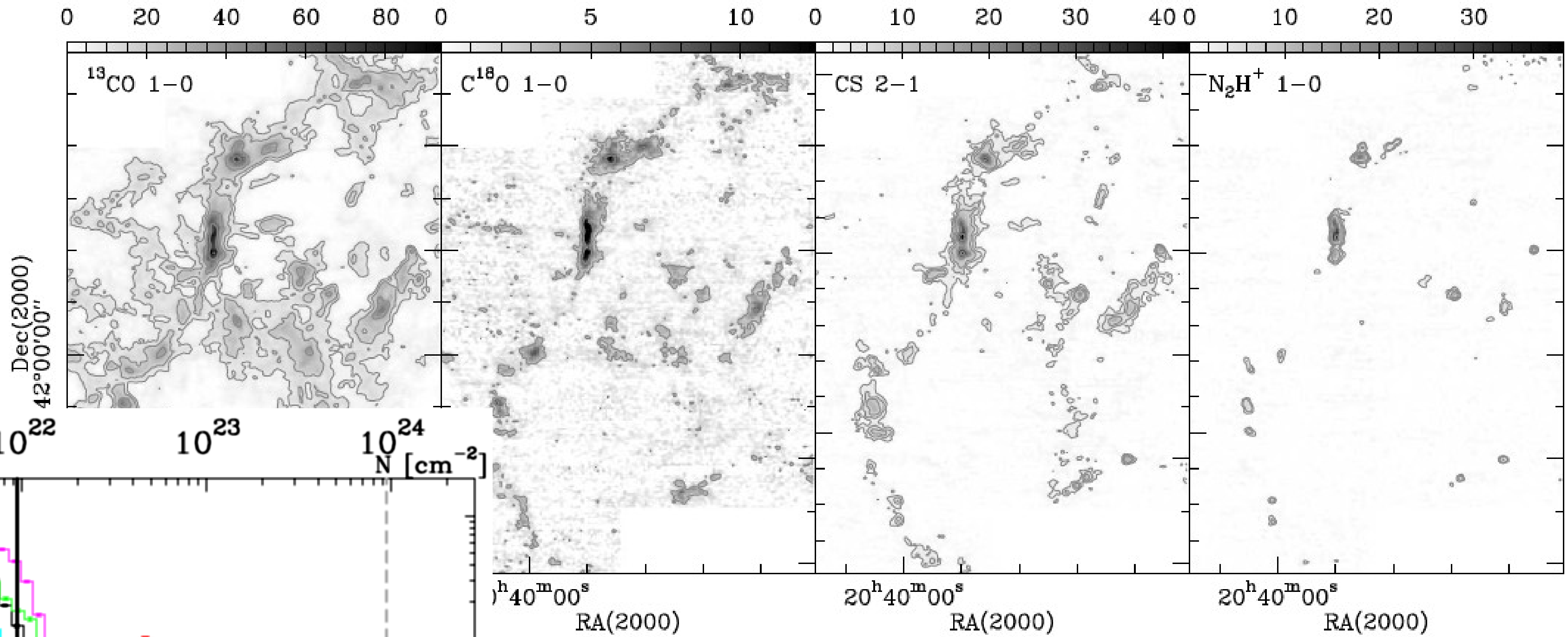


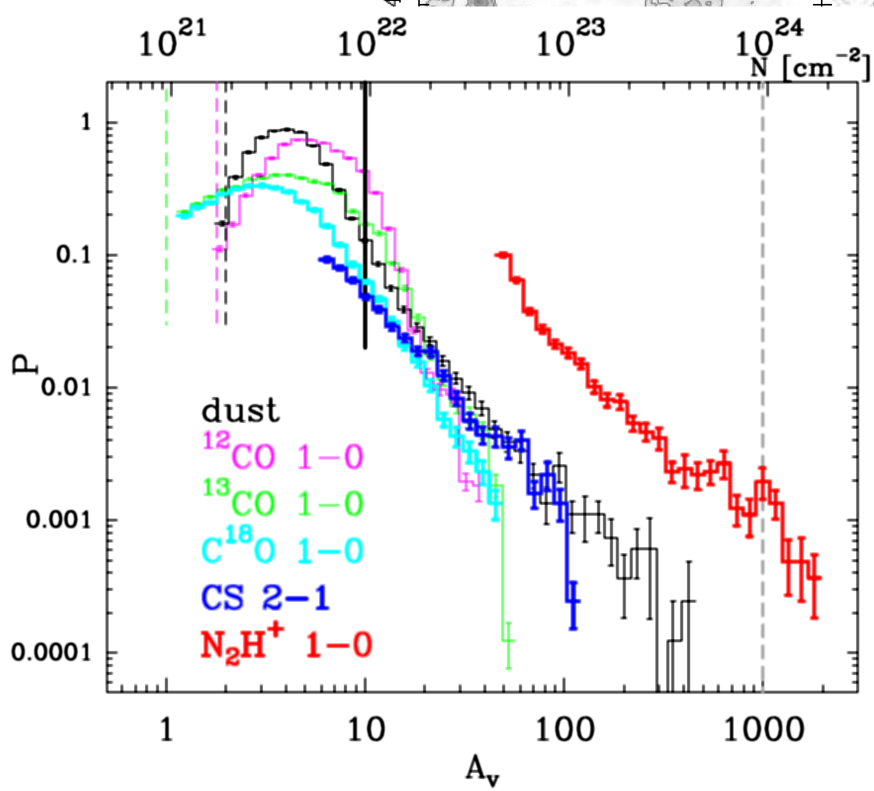
Total HI column density map

Way out

Combine information from different velocity-resolved tracers

Line observations in Cygnus and derived column-density PDFs (Schneider et al. (2015)



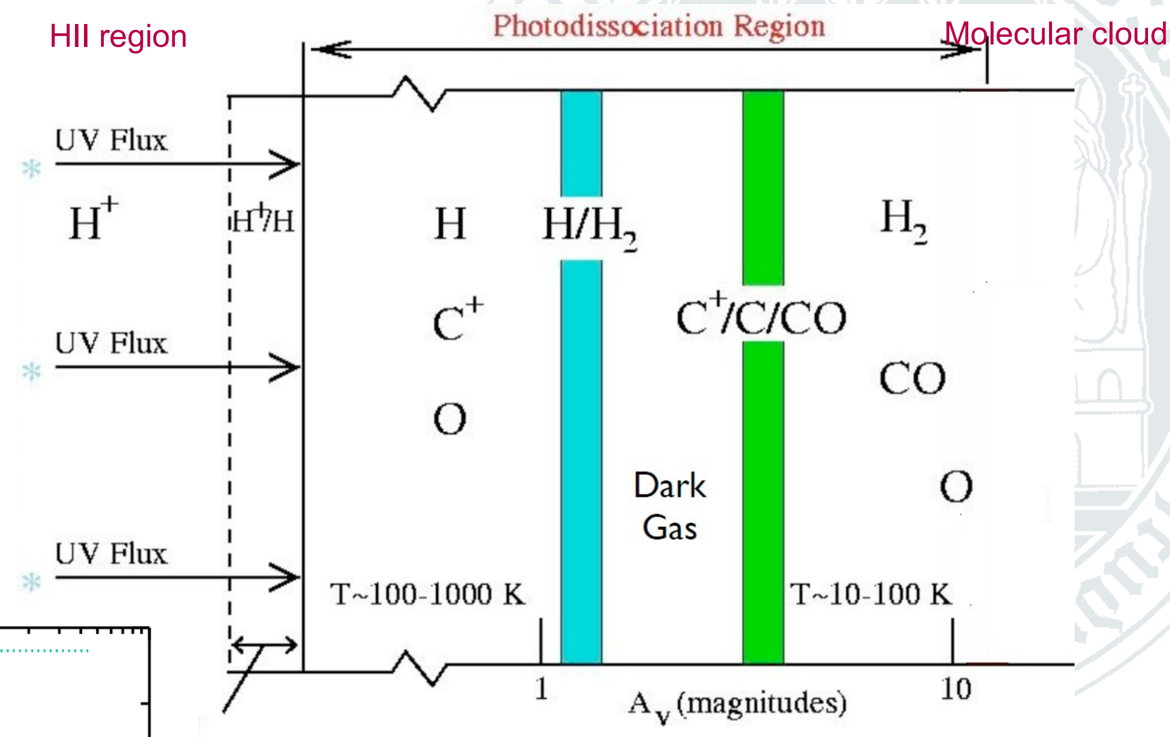


- Every species only traces a narrow dynamic range
  - CO isotopes miss high density tail
  - High density tracers miss log-normal
- Major uncertainty in the *X*-factors
- Molecules are not co-spatial due to chemical differentiation!

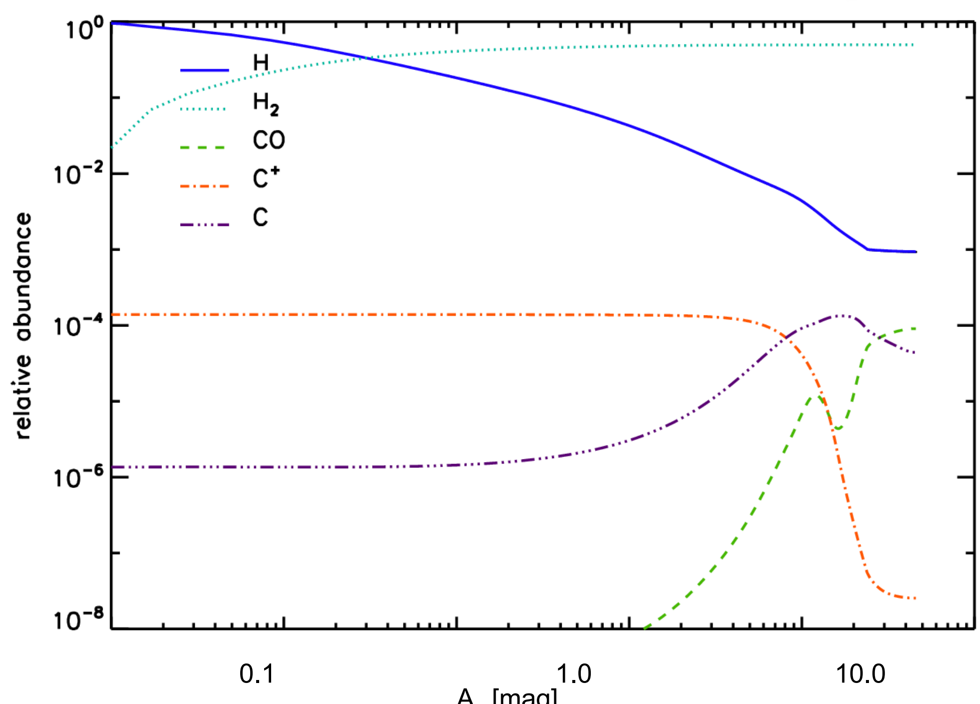
Chemical differentiation – consequence of varying density + UV field

Photodissociation regions:

- Layering of chemical transitions and temperatures
- Molecules dissociated at the cloud surfaces.
- Complex molecules only in the dense cores.



PDR structure (Hollenbach & Tielens 1999)

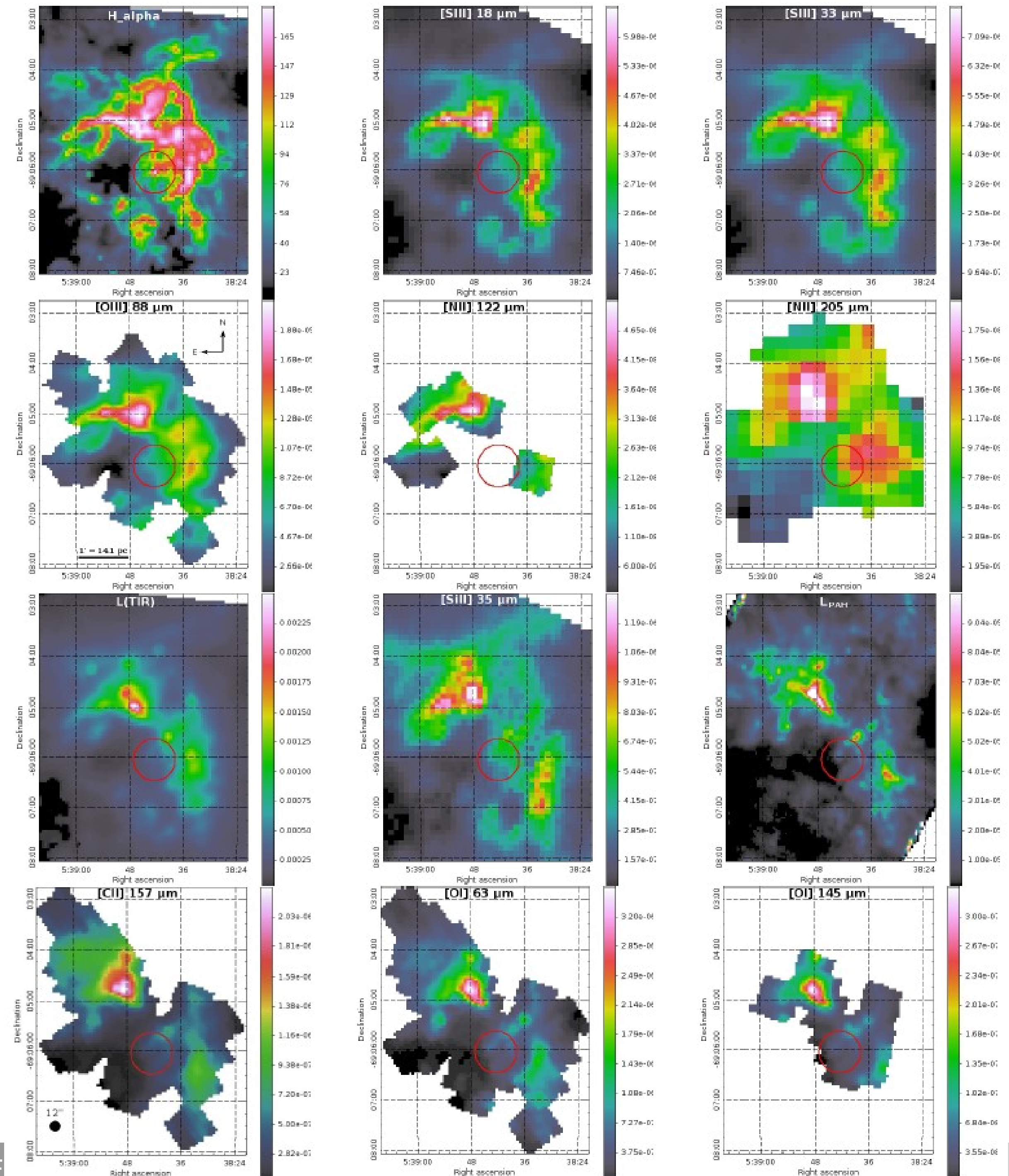


- Abundance of selected species as a function of optical depth from the cloud surface

(KOSMA-τ PDR model with $\chi = 1$, $M_{tot} = 100M_{O}$, $n = 500cm^{-3}$: Röllig et al. 2006)

Exploit chemical differentiation

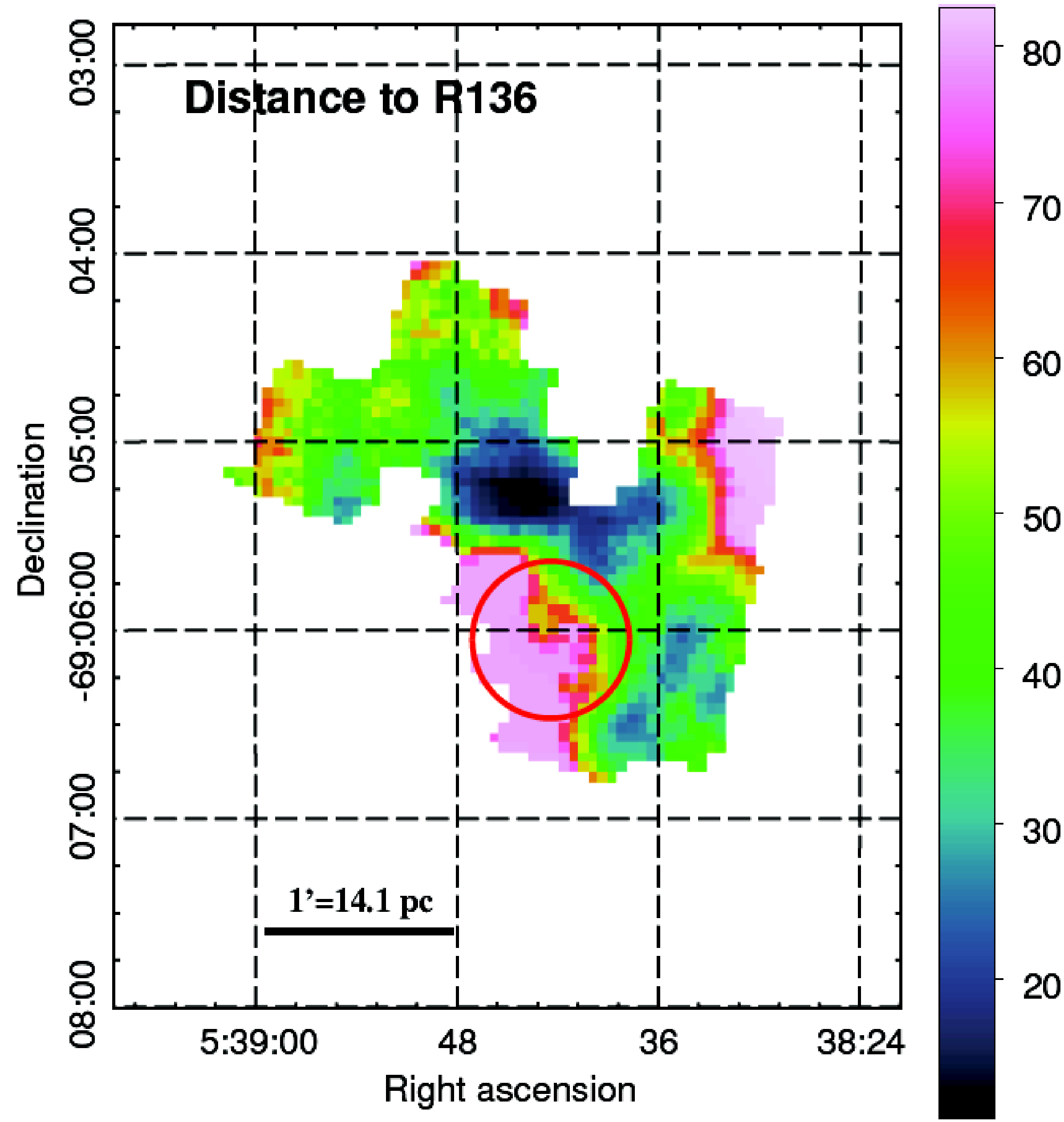
- Compare spatial distribution of many differentiated species
- Use dependence on UV flux as a distance estimate from illuminating sources
  - Provides 3-D model of the source
  - Solves contamination problem



Multi-line LMC 30Dor observations (Chevance et al. 2016)
Red circle = main illuminating source

Exploit chemical differentiation

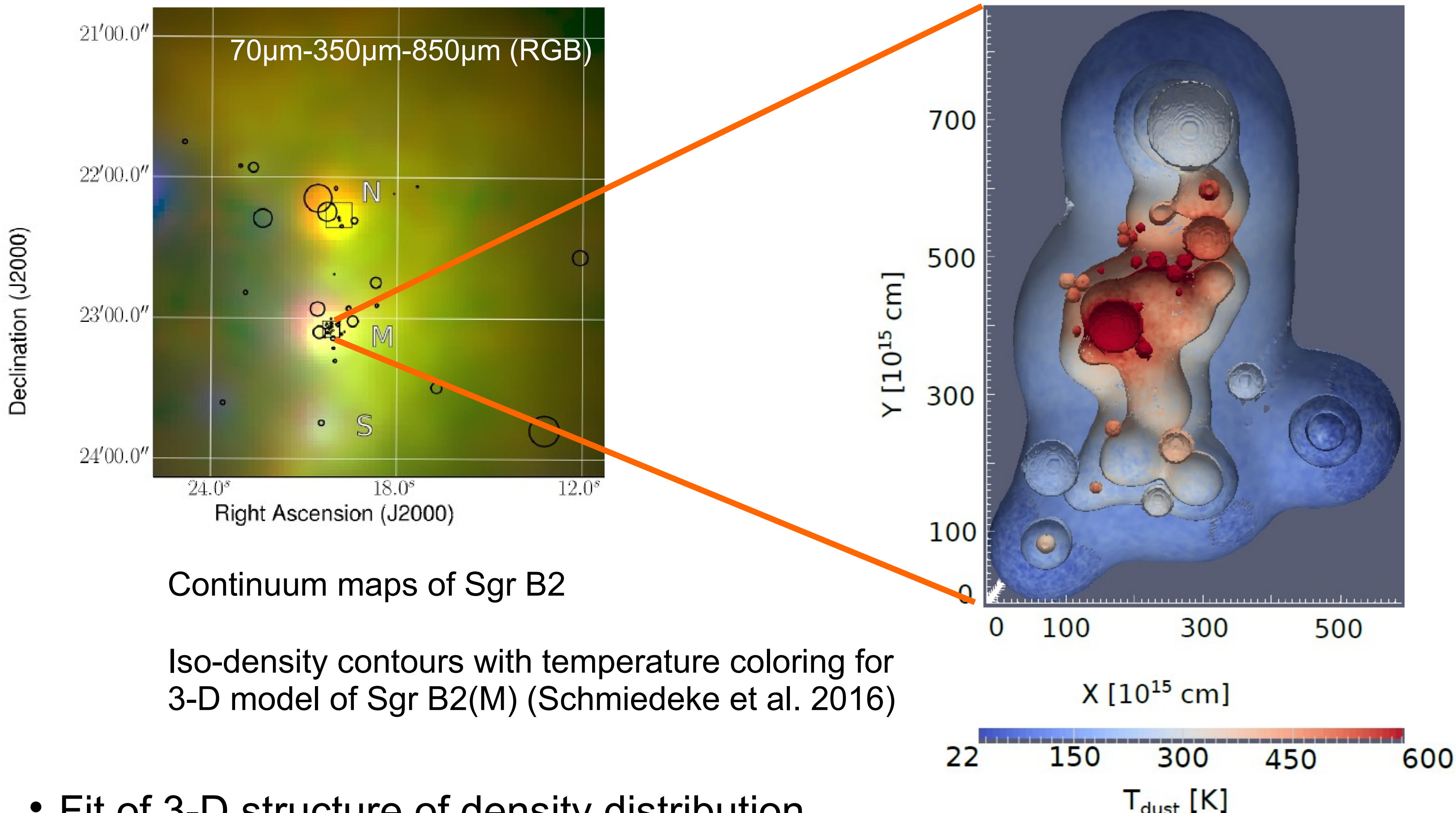
- Compare spatial distribution of many differentiated species
- Use dependence on UV flux as a distance estimate from illuminating sources
  - Provides 3-D model of the source
  - Solves contamination problem



Derived 3-D structure (Chevance et al. 2016)
Red circle = main illuminating source

Multi-source analysis

Combine with analysis of temperature gradients from radiative transfer



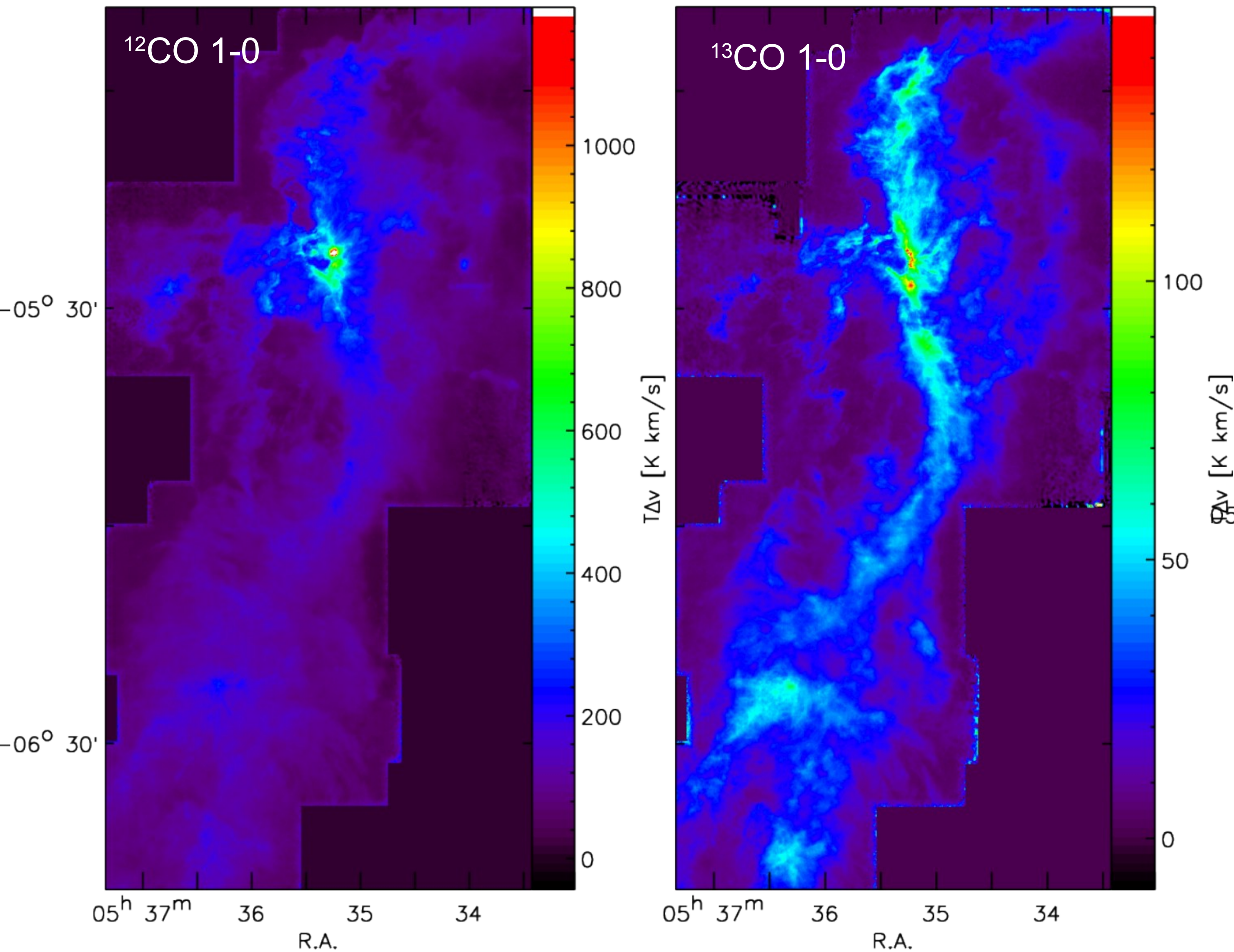
Continuum maps of Sgr B2

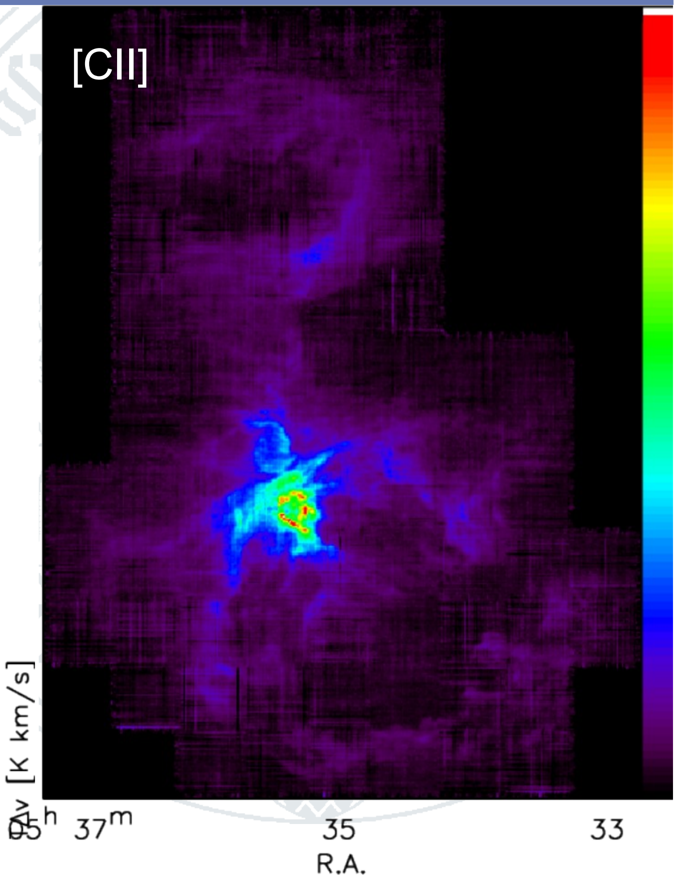
Iso-density contours with temperature coloring for 3-D model of Sgr B2(M) (Schmiedeke et al. 2016)

- Fit of 3-D structure of density distribution around all known heating sources
- So far velocity information not fully exploited yet!

The future

Different species and fully exploit velocity information



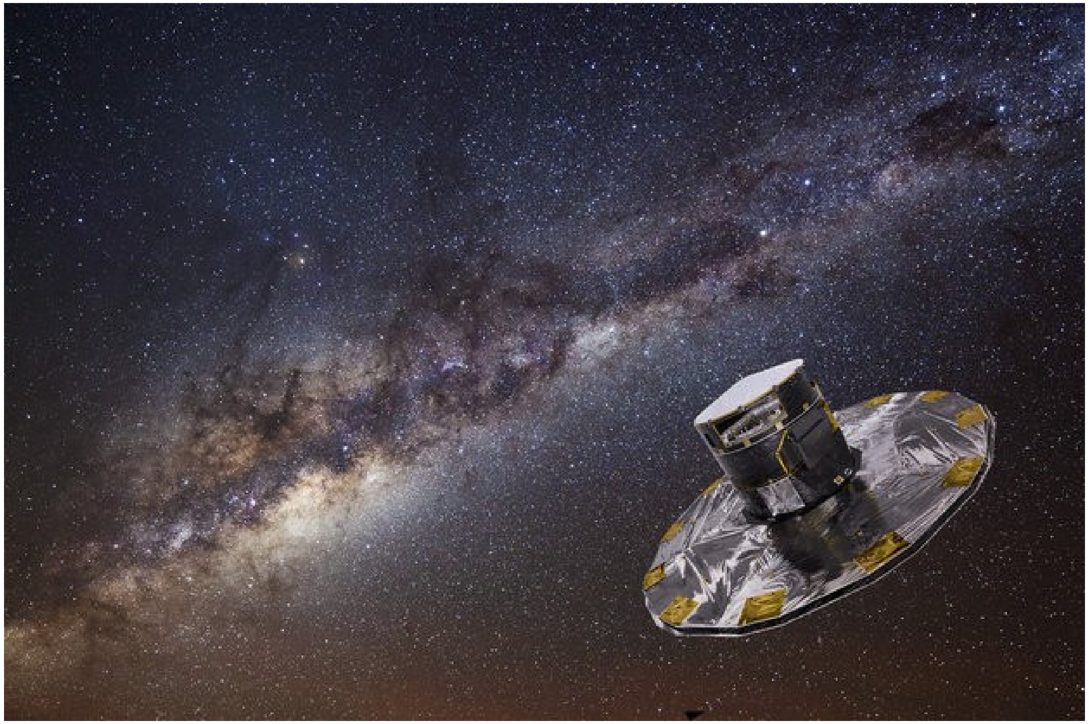


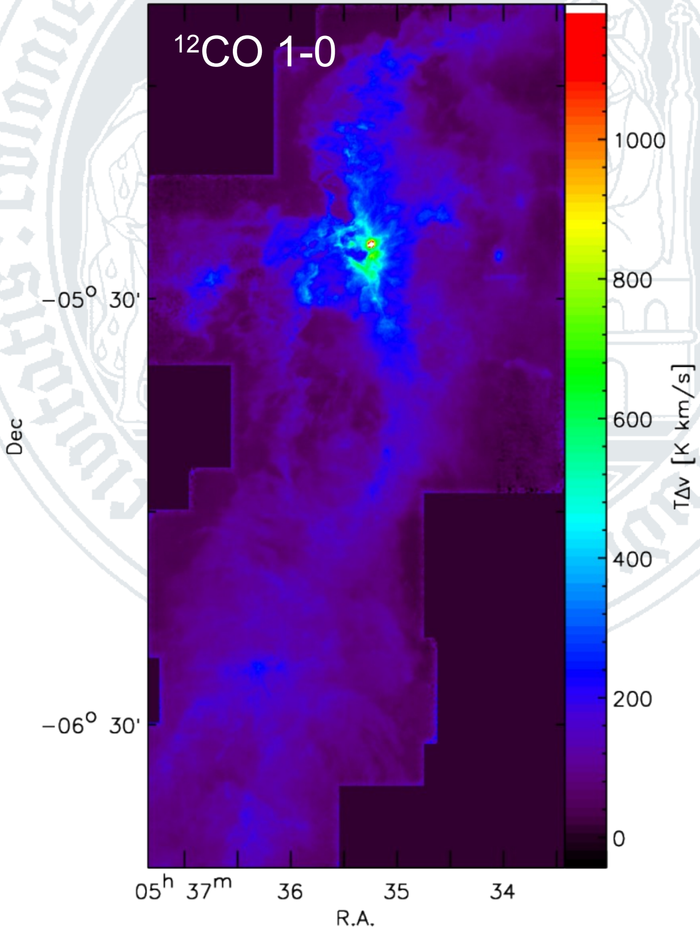
Orion Molecular cloud velocity channel maps

Every individual map contains more than a million spectra!

Different species and fully exploit velocity information

- 5-D problem:
  - Extended maps for many species (n > 10)
  - Fit individual velocity components
  - GAIA provides accurate 3-D locations of illuminating sources



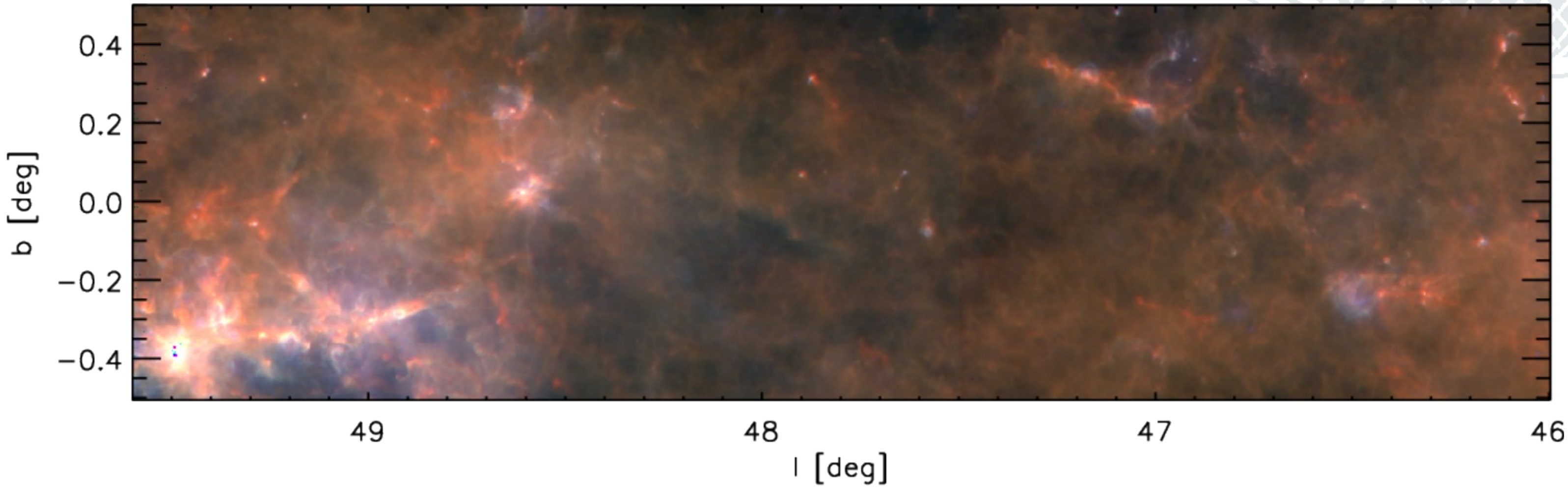


→ **Calibrate your 3-D models!**

Conclusions

Observed data always give you the whole picture

- You have to extract the limited view of your source of interest
  - No controlled boundary conditions
  - LOS confusion is unavoidable
    - Abundance and temperature variations along the LOS are normal
    - Velocity information helps – exploit the full line profiles



Conclusions

Observed data never give you the whole picture

- All observations provide a very limited dynamic range only
  - Line emission scans only a narrow density range
    - Optical depth + subthermal excitation
  - Noise and non-linearities are at best at the level of few percent
  - There are (almost) no absolute measurement
    - The sky reference is usually "polluted" as well
    - Large scale emission is extremely difficult to quantify
- Log-scales are often misleading!