HEXOS – Orion Bar

KOSMA-τ Modeling

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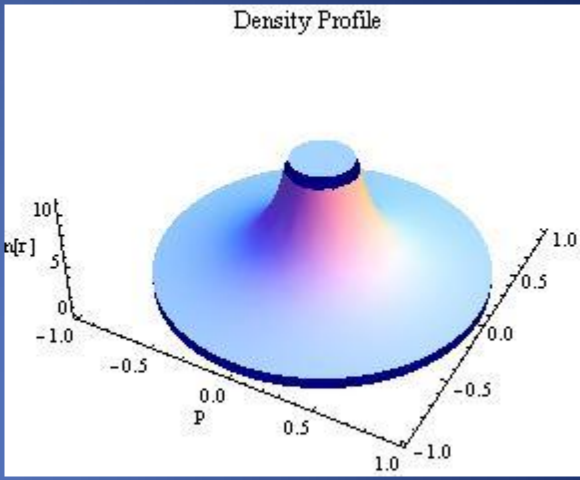
Modeling: KOSMA-τ PDR Code

- spherical geometry

$$n[r] = \begin{cases} n \left(\frac{r}{R}\right)^{-\alpha} & R\,R_{core} \le r \le R \\ n\,R_{core}^{-\alpha} & 0 \le r < R\,R_{core} \\ 0 & \text{True} \end{cases}$$

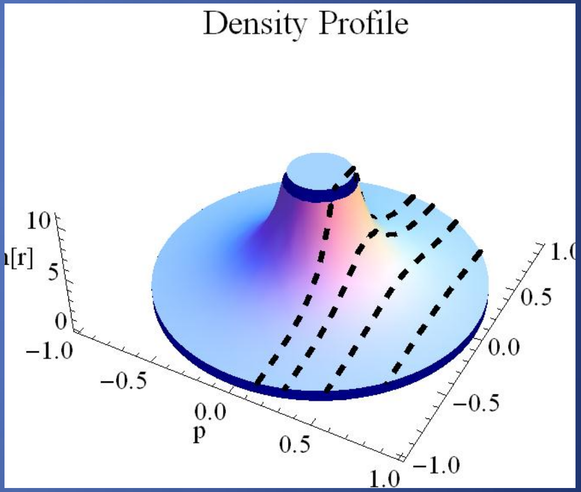


- isotropic illumination
- modular chemistry incl. isotopologues
- coupled with radiative transfer code (ONION, SimLine, etc.)
- self-consistently solves chemistry & energy balance

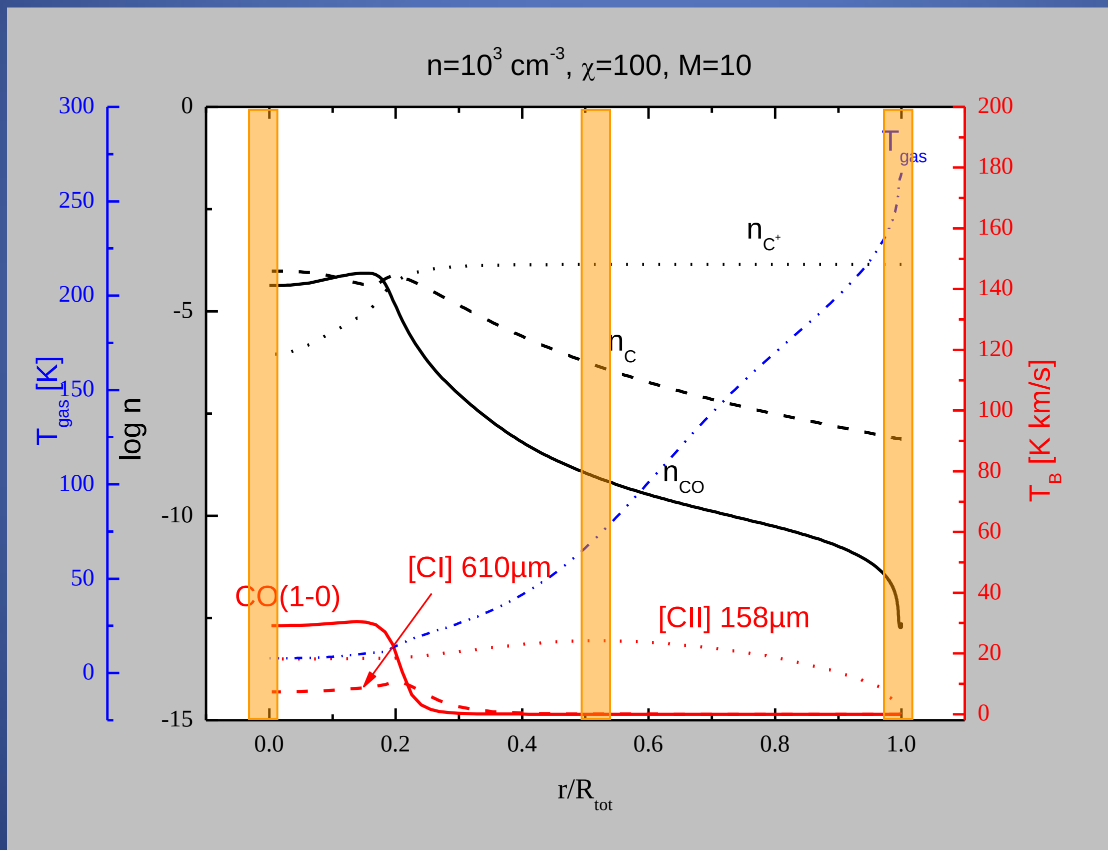
Modeling: KOSMA-τ PDR Code

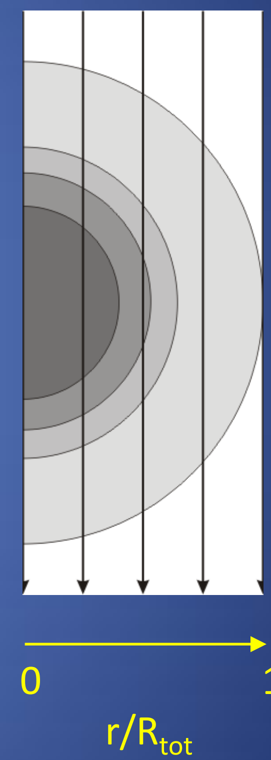
Output:

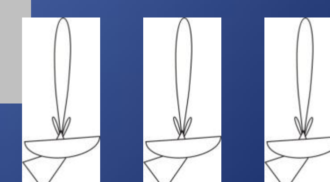
- density profile of all contained species
- temperature profile (gas, dust)
- excitation conditions (T_{ex}, etc.)
- clump-averaged quantities
  - column densities
  - AV
  - optical depths
  - intensities



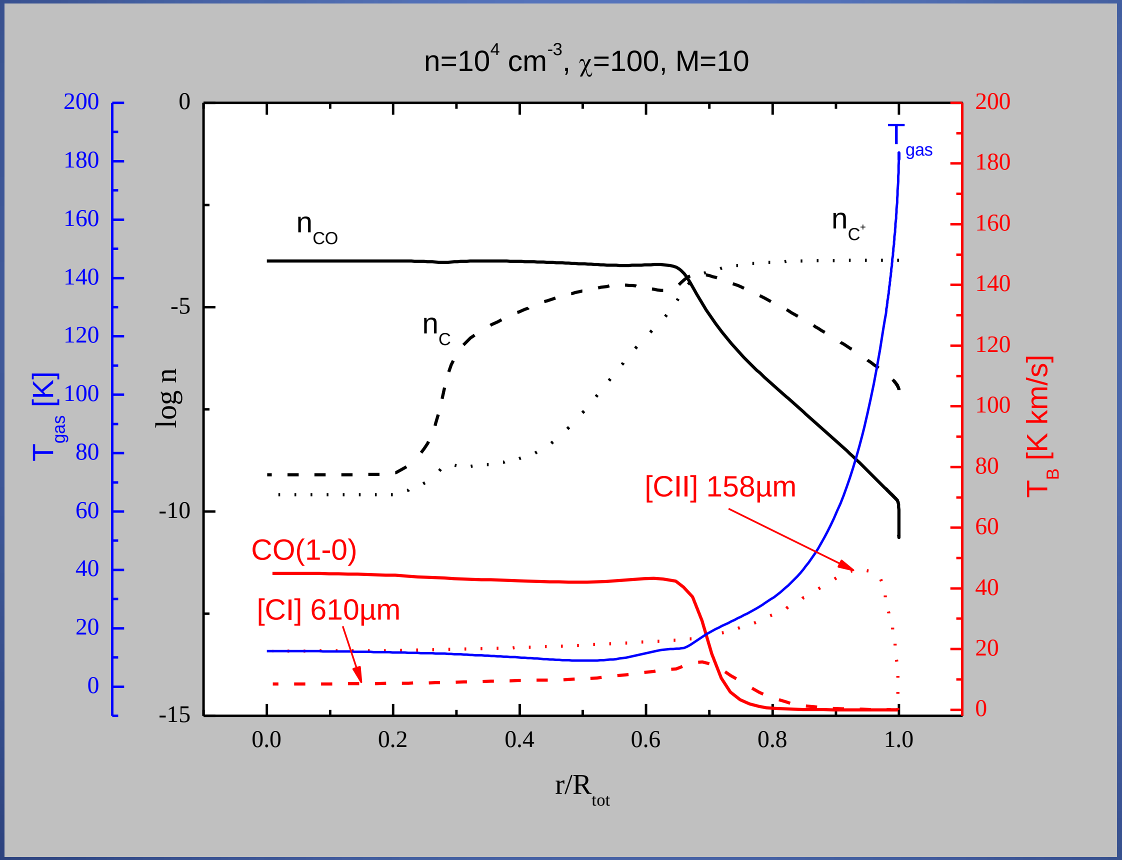
The KOSMA-τ Code

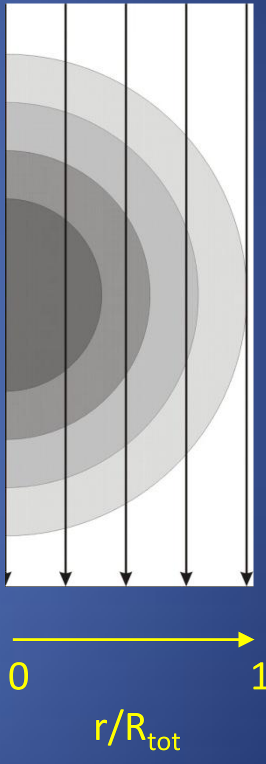






The KOSMA-τ Code



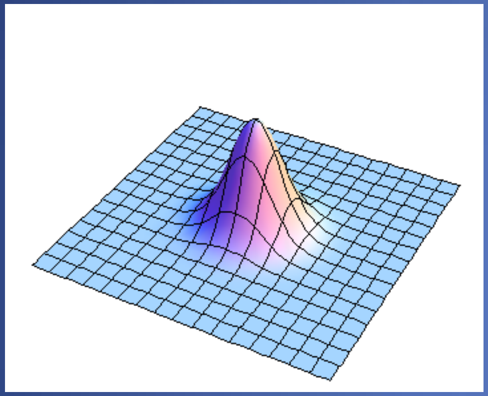


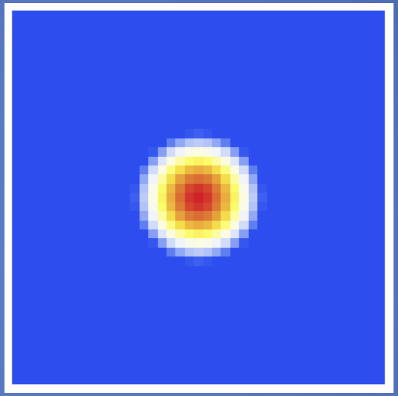
Orion Bar Modeling Workshop 17.-18. Feb. 2011 Paris

Recent updates

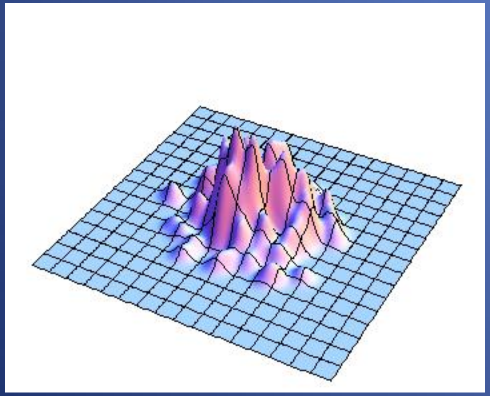
- – Updated PE heating (Weingartner & Draine 2001)
- – Improved dust handling (various compositions, ..)
- – Clumpy media (post-computational superposition)
- – Improved model fitting tools
- – Upgrade to UDfA0x
- – Incorporation of isotopomers into UDfA0x (automated)

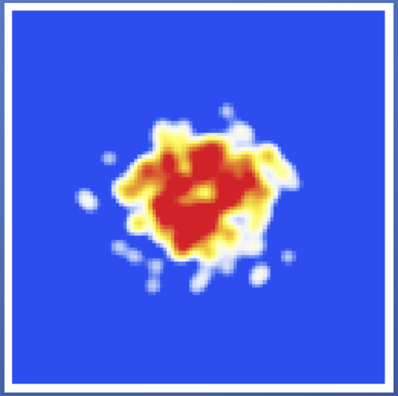
Clumpy Media





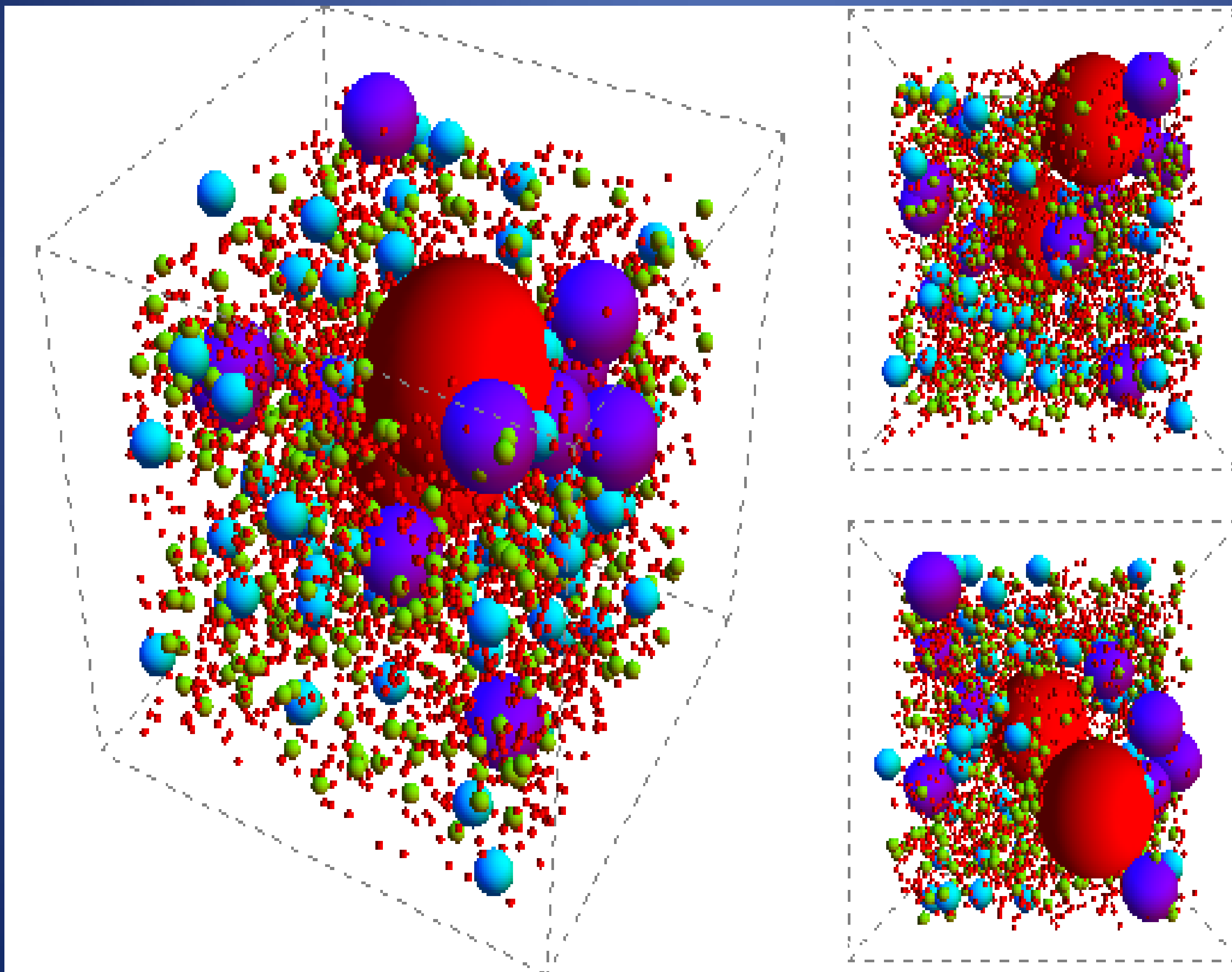
single clumps with Gaussian emission pattern





superposition of 200 Gaussian clumps

Clumpy Clouds via Superposition of Individual Clouds



$dN/dM \sim M^{-1.8}$

$M/M_{\odot}$	N
100	2
10	13
1	80
0.1	502
0.01	3170

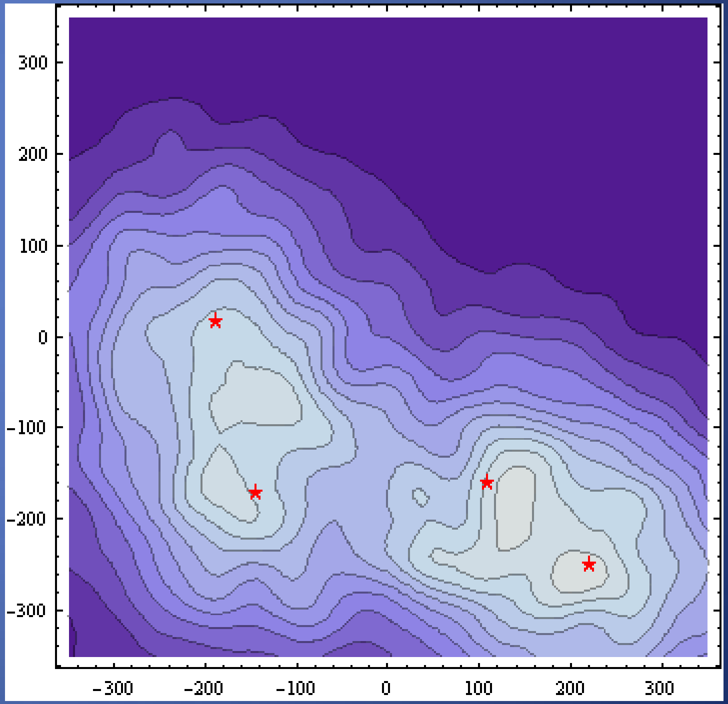
$M_{tot}=673\ M_{\odot}$

Clumpy Media

- random realisation of an ensemble with $M_{tot}=10^4 M_\odot$ (subdivided into 4 condensations)

Pillars in Rosette (HOBYS team: Motte et al. 2010)

random distribution



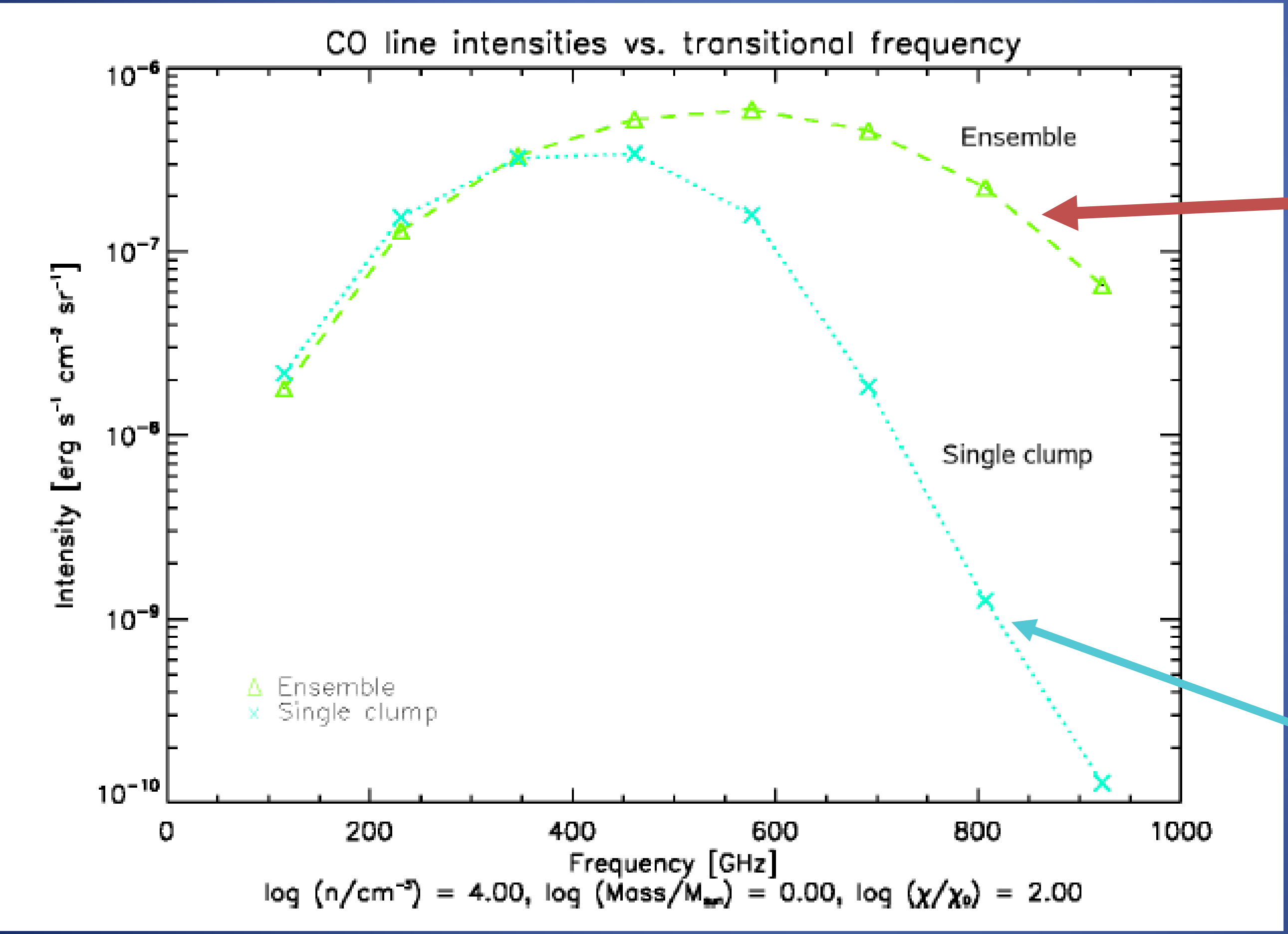
observed with a 45'' beam

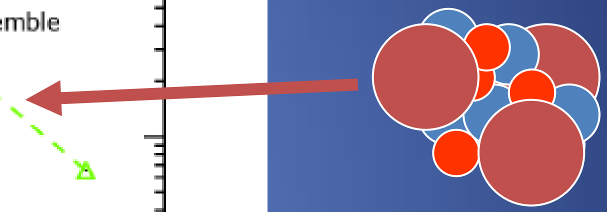
Effects of Clumpiness

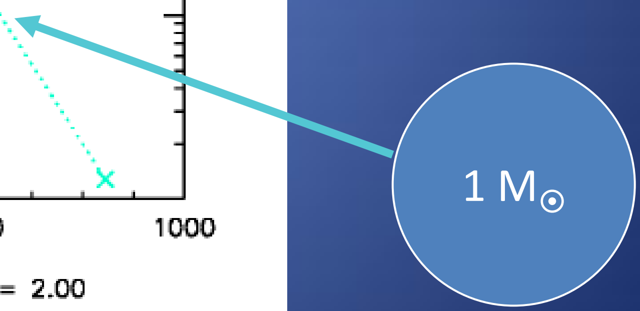
- A single model cloud has very different properties compared to a clumpy cloud ensemble of the same mass.
  - very many small clumps, few large clumps
  - much more surface:
  - larger volume fraction is reached by FUV
  - more hot gas compared to monolithic cloud
  - e.g. stronger emission of high J CO lines

CO Emissions from Clumps

High-J CO lines can be excited due to clumpiness







UMIST/UDfA - Isotopomers

- Upgrade from UMIST95/99 to UDfA0x
  - reactions are now provided with multiple sets of reaction rates (valid for different temperature ranges). For example:

C + CO → CO + O

T = 10...300K

α=4.7E-4

β=-0.34

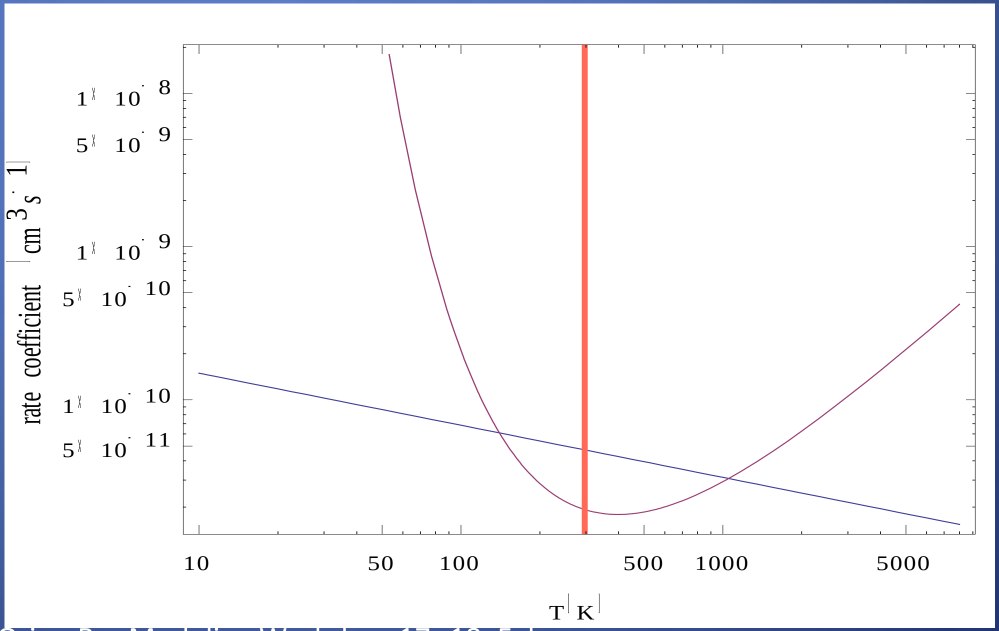
γ=0

T = 295...8000K

α=2.48E-2

β=1.54

γ=-613



UMIST/UDfA - Isotopomers

- Insert a single ^{13}C and/or ^{18}O into the UDfA reeactions
- Automatic introduction of isotopes into chemical compounds is not easy. Simple permutation may lead to undesired reactions

blind permutation

CH3	CN$^-$	· · 〉	CH3CN	e$^-$
CH3	13CN$^-$	· · 〉	CH313CN	e$^-$
CH3	13CN$^-$	· · 〉	13CH3CN	e$^-$
13CH3	CN$^-$	· · 〉	CH313CN	e$^-$
13CH3	CN$^-$	· · 〉	13CH3CN	e$^-$

‚cleverer‘ permutation

CH3	CN$^-$	· · 〉	CH3CN	e$^-$
CH3	13CN$^-$	· · 〉	CH313CN	e$^-$
13CH3	CN$^-$	· · 〉	13CH3CN	e$^-$

functional group binding needs to be kept

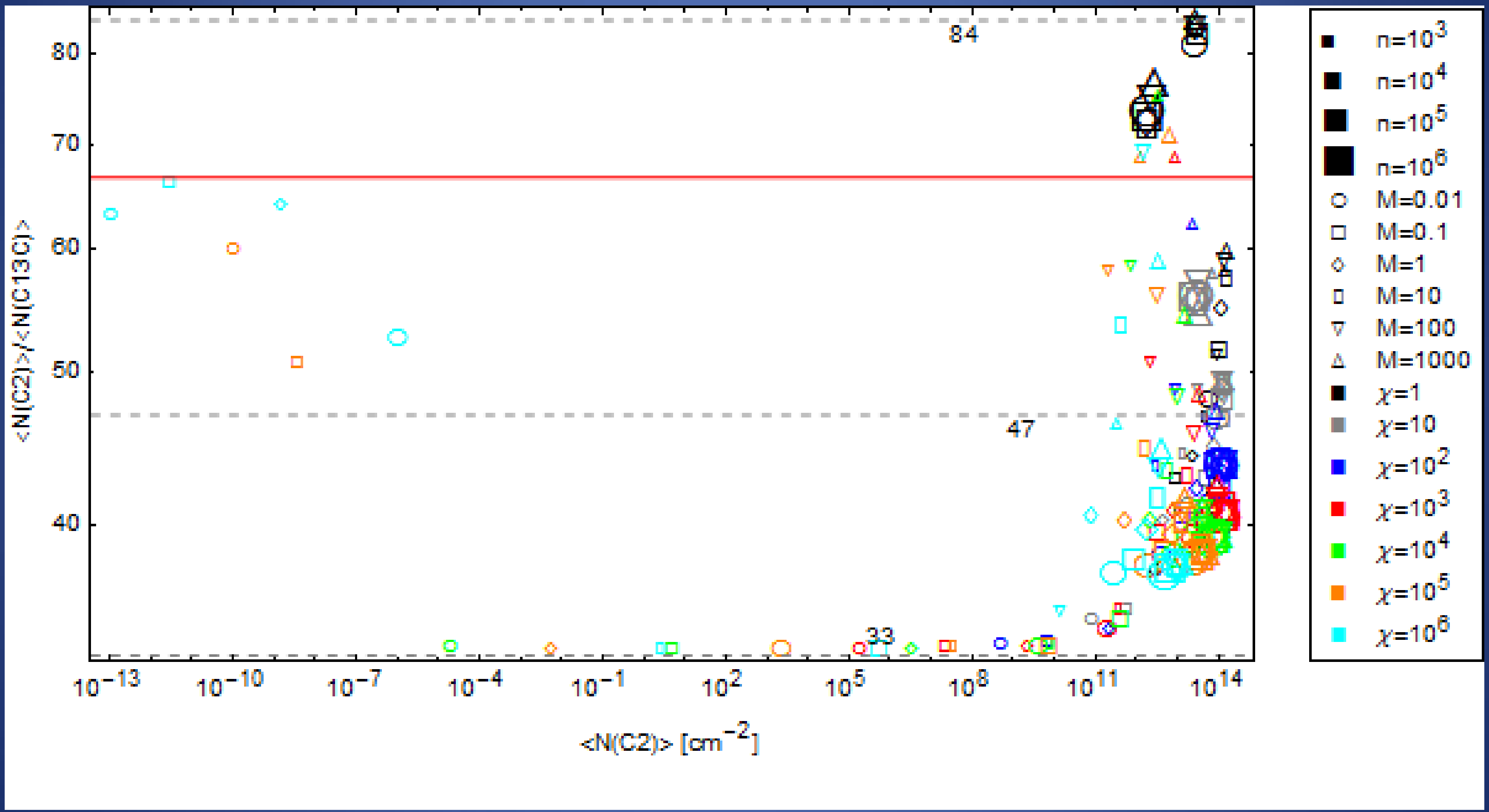
UMIST/UDfA - Isotopomers

Complexity is large. Blind permutation of UDfA06 leads to ~50000 reactions! Automatic house-keeping necessary.

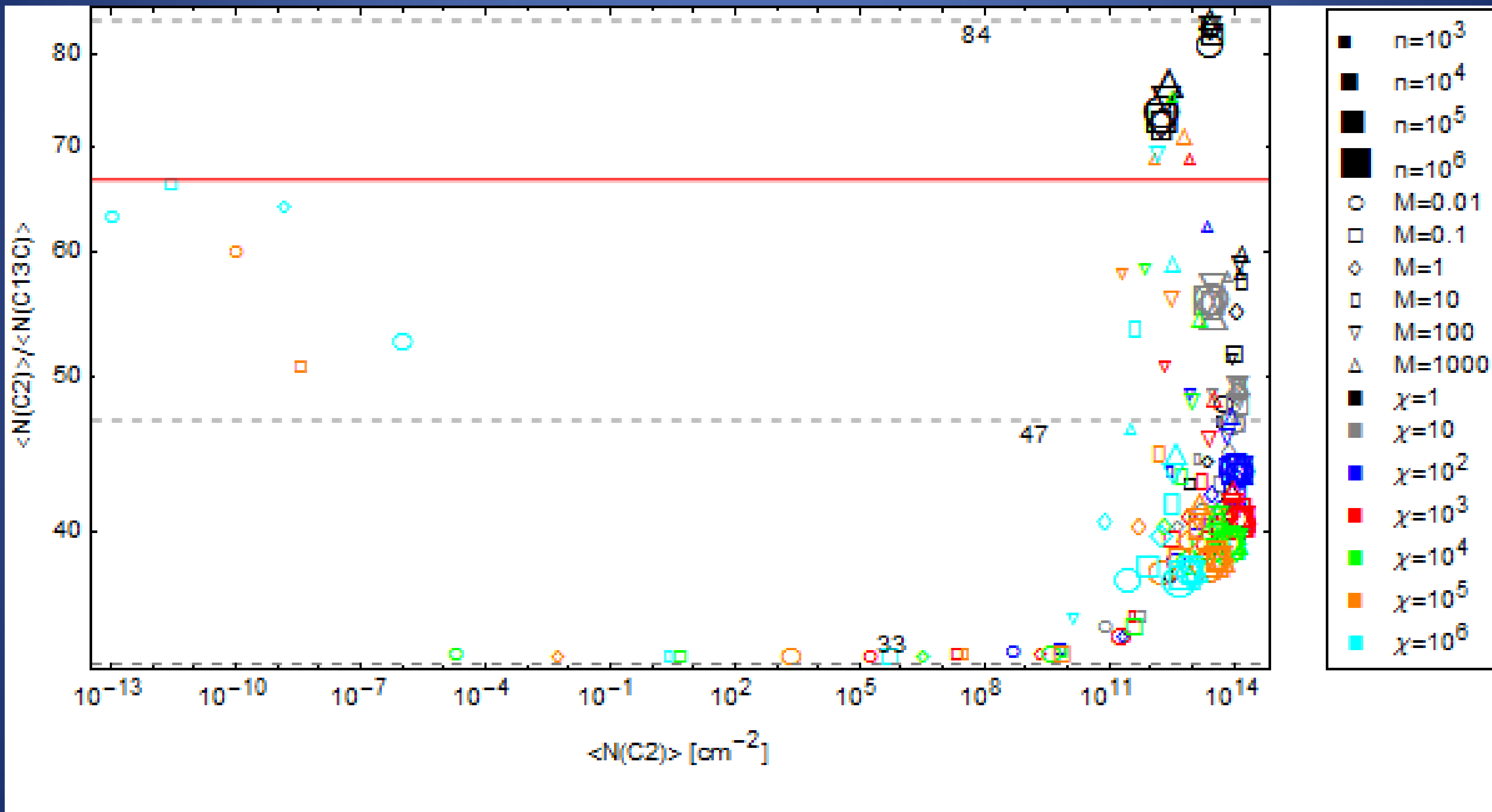
CH3COCH3+	e-	· · 〉	CO	CH3	CH3
CH3CO13CH3+	e-	· · 〉	CO	CH3	13CH3
CH3CO13CH3+	e-	· · 〉	CO	13CH3	CH3
CH3CO13CH3+	e-	· · 〉	13CO	CH3	CH3
CH3C18OCH3+	e-	· · 〉	C18O	CH3	CH3
CH3C18O13CH3+	e-	· · 〉	C18O	CH3	13CH3
CH3C18O13CH3+	e-	· · 〉	C18O	13CH3	CH3
CH3C18O13CH3+	e-	· · 〉	13C18O	CH3	CH3
CH313COCH3+	e-	· · 〉	CO	CH3	13CH3
CH313COCH3+	e-	· · 〉	CO	13CH3	CH3
CH313COCH3+	e-	· · 〉	13CO	CH3	CH3
CH313C18OCH3+	e-	· · 〉	C18O	CH3	13CH3
CH313C18OCH3+	e-	· · 〉	C18O	13CH3	CH3
CH313C18OCH3+	e-	· · 〉	13C18O	CH3	CH3
13CH3COCH3+	e-	· · 〉	CO	CH3	13CH3
13CH3COCH3+	e-	· · 〉	CO	13CH3	CH3
13CH3COCH3+	e-	· · 〉	13CO	CH3	CH3
13CH3C18OCH3+	e-	· · 〉	C18O	CH3	13CH3
13CH3C18OCH3+	e-	· · 〉	C18O	13CH3	CH3
13CH3C18OCH3+	e-	· · 〉	13C18O	CH3	CH3

CH3COCH3+	e-	· · 〉	CO	CH3	CH3
CH3CO13CH3+	e-	· · 〉	CO	13CH3	CH3
CH3C18OCH3+	e-	· · 〉	C18O	CH3	CH3
CH3C18O13CH3+	e-	· · 〉	C18O	13CH3	CH3
CH313COCH3+	e-	· · 〉	13CO	CH3	CH3
CH313C18OCH3+	e-	· · 〉	13C18O	CH3	CH3
13CH3COCH3+	e-	· · 〉	CO	13CH3	CH3
13CH3C18OCH3+	e-	· · 〉	C18O	13CH3	CH3

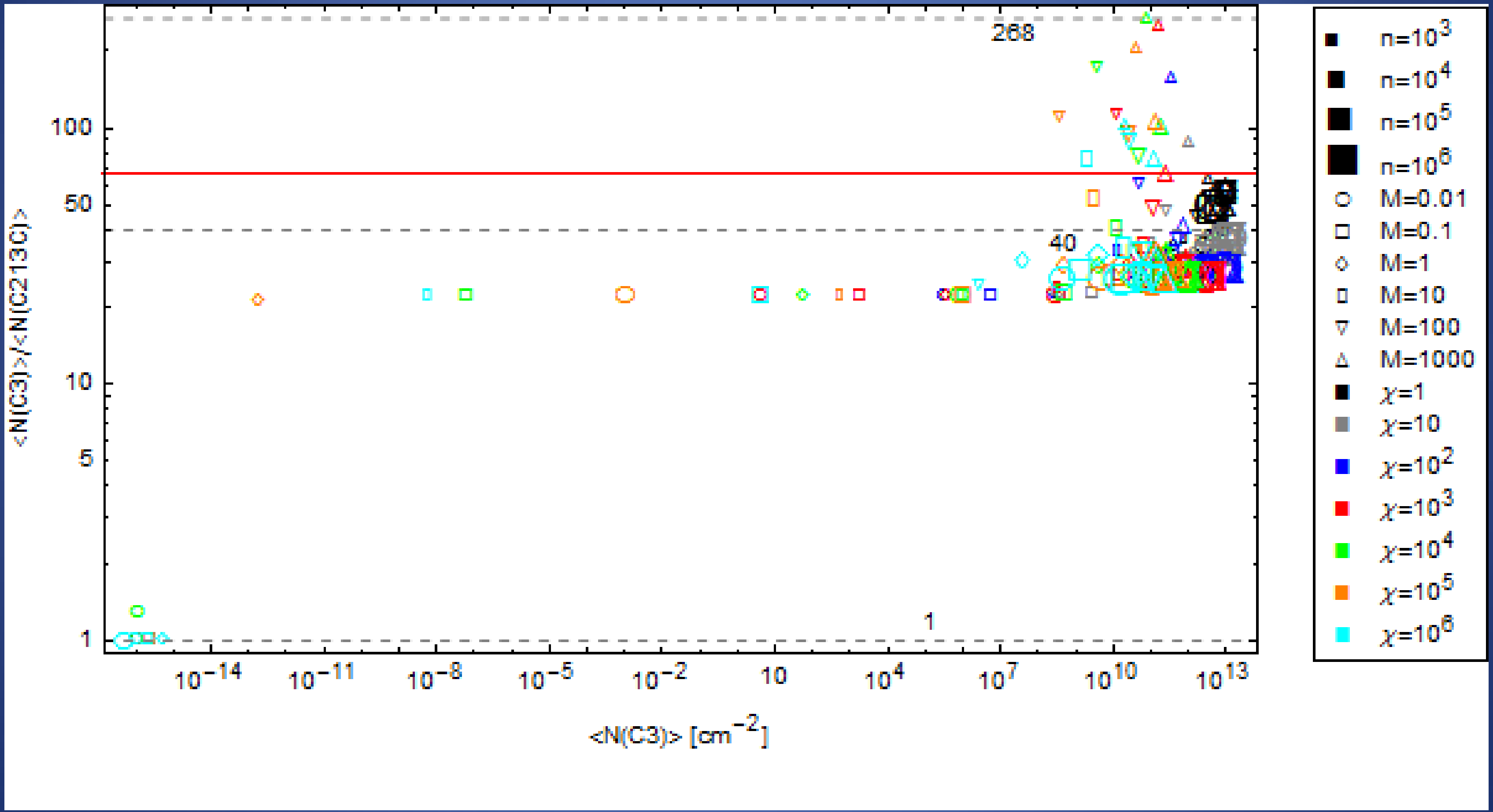
13C Fractionation



13C Fractionation

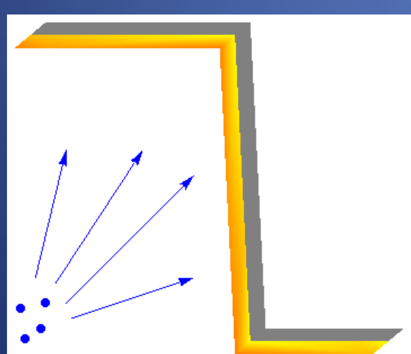


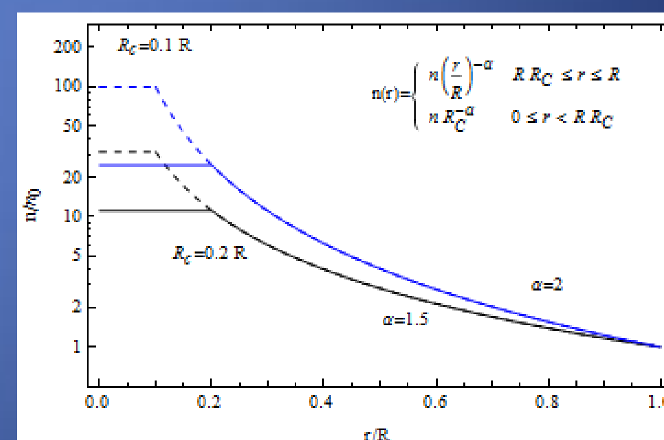
13C Fractionation



Work in progress

- dust continuum emission
- dust temperature calculation
- ➢ surface chemistry
- variations of the density structure
- geometrical modeling





Quick literature data look-up (all in K km/sec)

- ^{12}CO
  - 1-0: 190±130 (Tauber 1994), 60±25 (Omodaka
  - 2-1: 280±120 (White & Sandell 1995)
  - 3-2: 240±90 (Hogerheijde (1995)
  - 4-3: 400±150 (Wilson 2001), 125±60 (White & Sandell (1995))
  - 5-4: 360±40 (Wirström, 2006)
  - 6-5: 415±100 (Lis 1997)
  - 7-6: 470±120 (Wilson 2001)
  - 9-8: 265±90 (Marrone 2004)
  - 14-13: 117±30 (Sempere 2000), 73±25 (Stacey 1993)

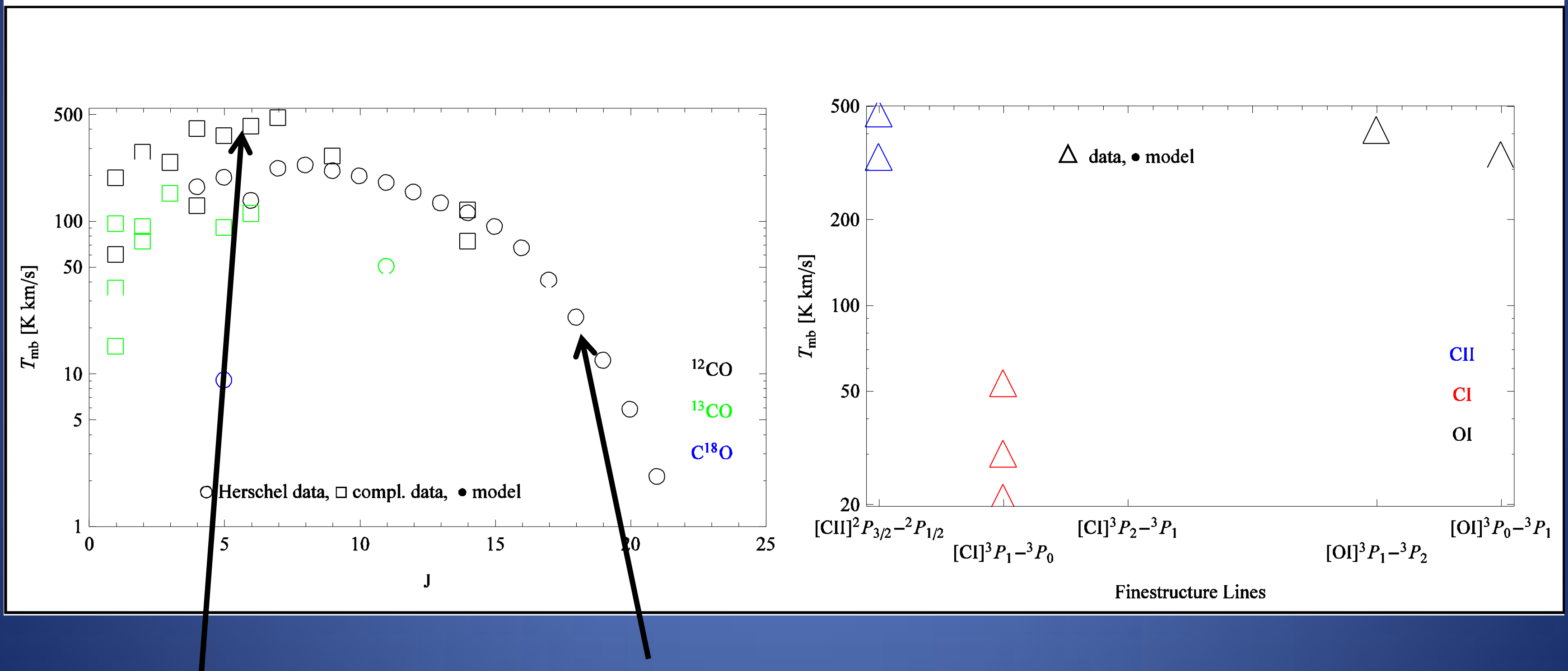
sometimes data from different authors appears to be inconsistent
→ needs checking

- ^{13}CO
  - 1-0: 95±30 (Tauber 1994), 36±15 (Ikeda 2002), 15±8 (Omodaka (1994)
  - 2-1: 91±25 (White & Sandell 1995), 73±30 (Keene (1996)
  - 3-2: 150±100 (van der Wiel 2009)
  - 5-4: 90±10 (Wirström 2006)
  - 6-5: 111±80 (Lis 1997)

- [CI] (1-0): 53±30 (White & Sandell 1995, and Keene 1996), 30±10 (Ikeda 2002), 21±8 (Hogerheijde 1995 and Tauber 1995)
- [CII] 158μ: 470±250 (Herrmann 1997), 330±110 (Mookerjea 2003)
- [OI] 63μ: 410±100 (Herrmann 1997)
- [OI] 145μ: 335±100 (Herrmann 1997)

Orion Bar Data

Complementary observations show a large spread in intensities, e.g. ^{13}CO J=1-0

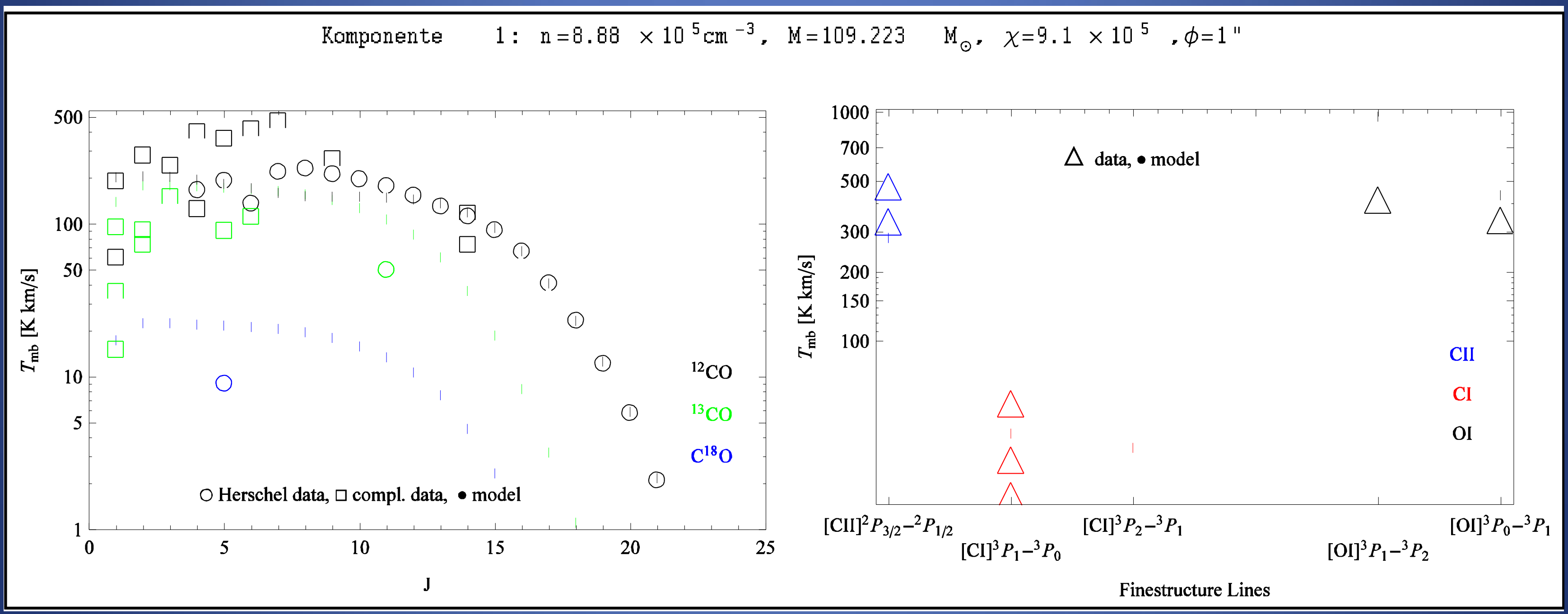


literature data, PACS & SPIRE data,

Model Remarks

- Large uncertainties in applied Herschel data values (calibration)
- Complementary data was only quickly picked up from the literature and shows large spread in the actual values → careful review needed
- So far we only used the SPIRE & PACS data to achieve a first fit. The complementary data points are just plotted to allow a first assessment of the fit.
- We always fit absolute intensities/fluxes, we don‘t fit line ratios.
- Assumption: $T_{mb}(C^{18}O)^{model} = 1/8\ T_{mb}(^{13}CO)^{model}$

Single Component non-Clumpy Model

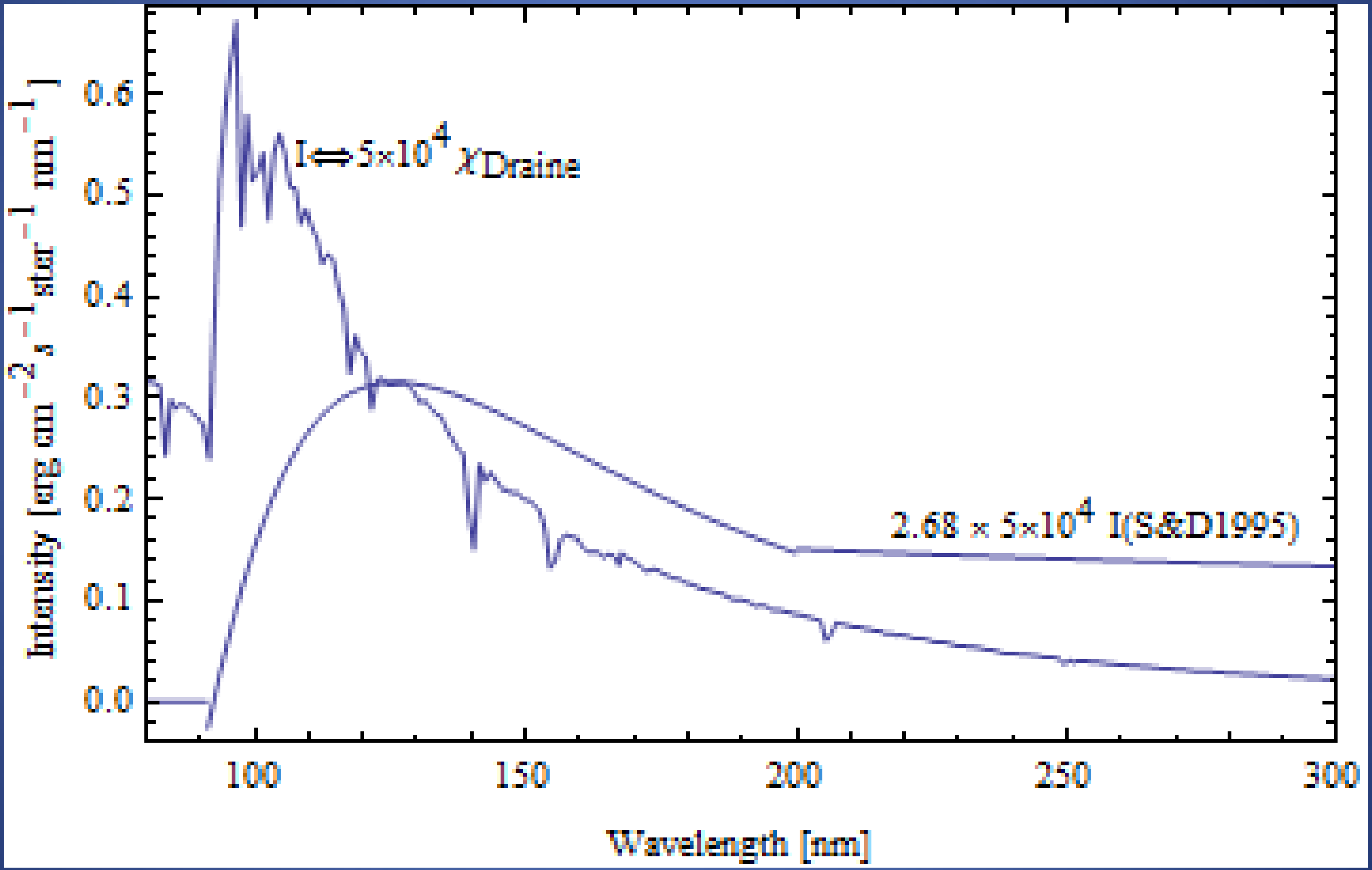


high-J ^{12}CO lines well fitted, ^{13}CO not well reproduced

Finestructure lines met relatively well

but very large χ neccessary.

FUV Differences

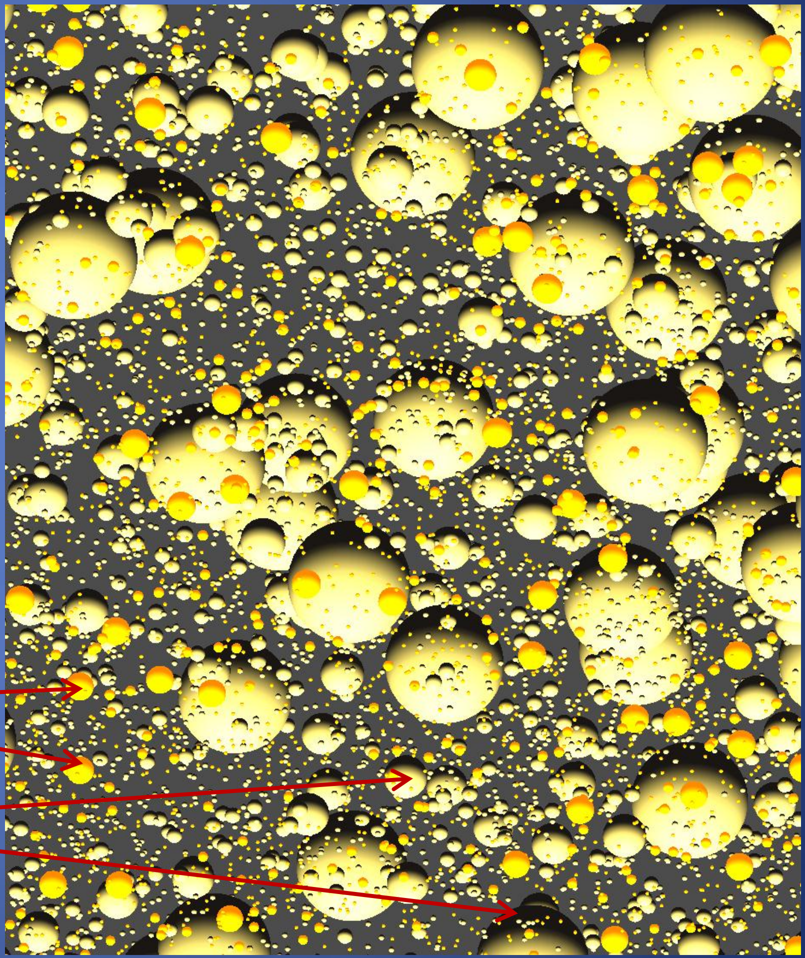


Single component summary

- To reproduce the very high J transitions a simple model requires very strong FUV illumination, which is inconsistent with the local conditions.
- The model mass is very large.
- [OI] lines are always a problem in the PDR fits, and will be ignored for the moment.

2-Comp. Clumpy Model Approach

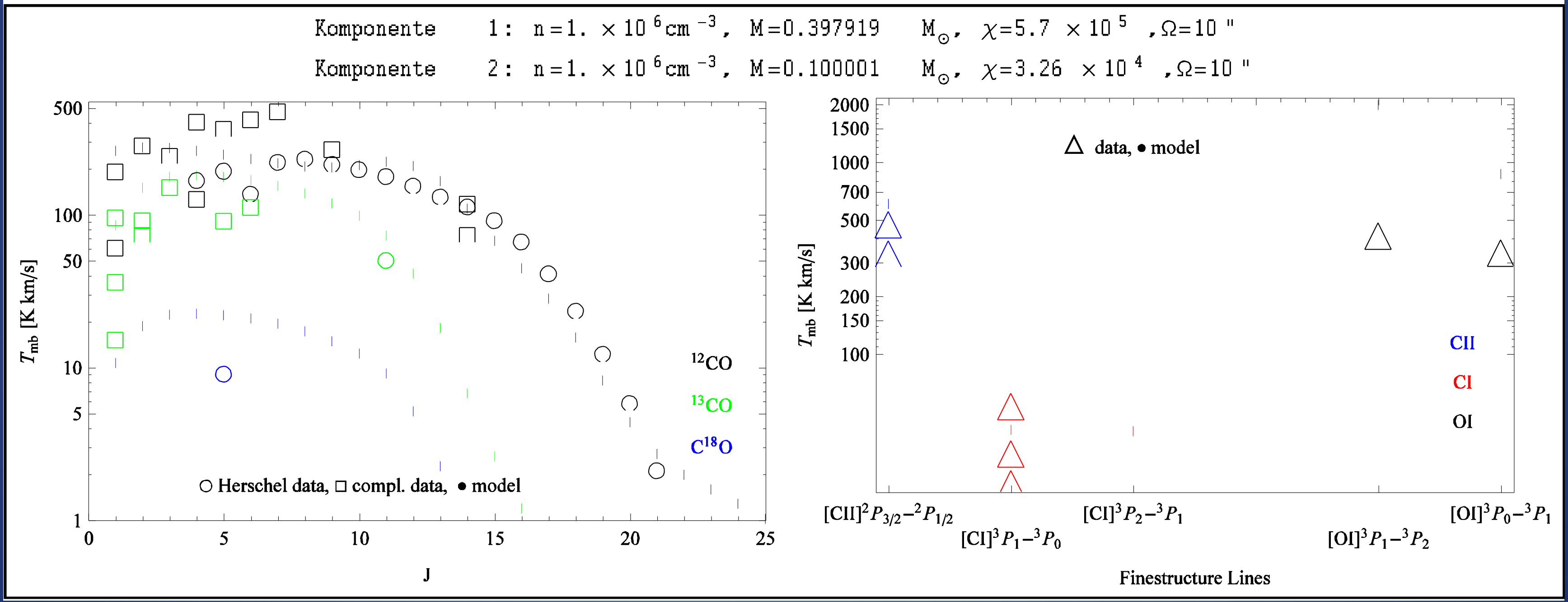
- We assume a stratification of 2 clumpy layers
- deeper layer see a weaker FUV field due to attenuation



yellow: closer to the FUV source

beige: further away from the FUV source

2-Component, Clumpy Model



^{12}CO lines well fitted. ^{13}CO not too bad.

Finestructure lines met relatively well.

observed mean col. density of 6.5e22 cm^{-2} and a (9.6“)² pixel implies a mass of 0.2 $M_\odot$ 👍

Component Summary

	component 1	component 2
mean density	1e6 cm^{-3}	1e6 cm^{-3}
total mass , {min,max clump mass}	0.4 $M_\odot$ {0.001 $M_\odot$, 10 $M_\odot$}	0.1 $M_\odot$ {0. 1 $M_\odot$, 10 $M_\odot$}
FUV (Draine)	5.7e5	3.3e4
area filling (1)	1.9	0.3
volume filling (2)	0.056	0.014

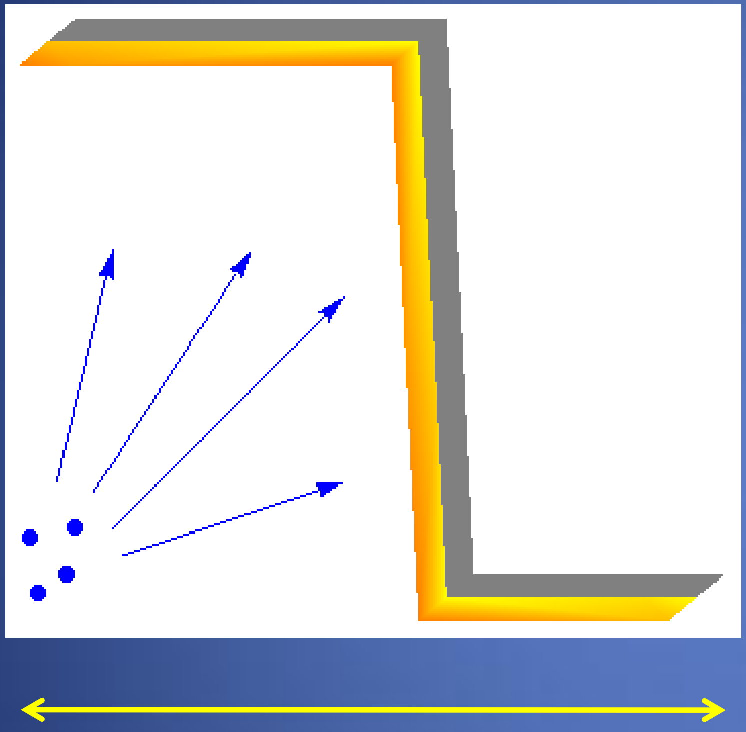
We assume a clump mass power index of 1.8, and a mass size power index of 2.3.

Problems:

- max. clump masses of both components are too large compared to the total mass -> requires updated model grid
- FUV still too large

(1) ensemble solid angle/(solid angle of (9.6“ × 9.6“ × 0.6 pc) box)
(2) ensemble volume/(box volume of 9.6“ side length in 415 pc distance)

Across the bar

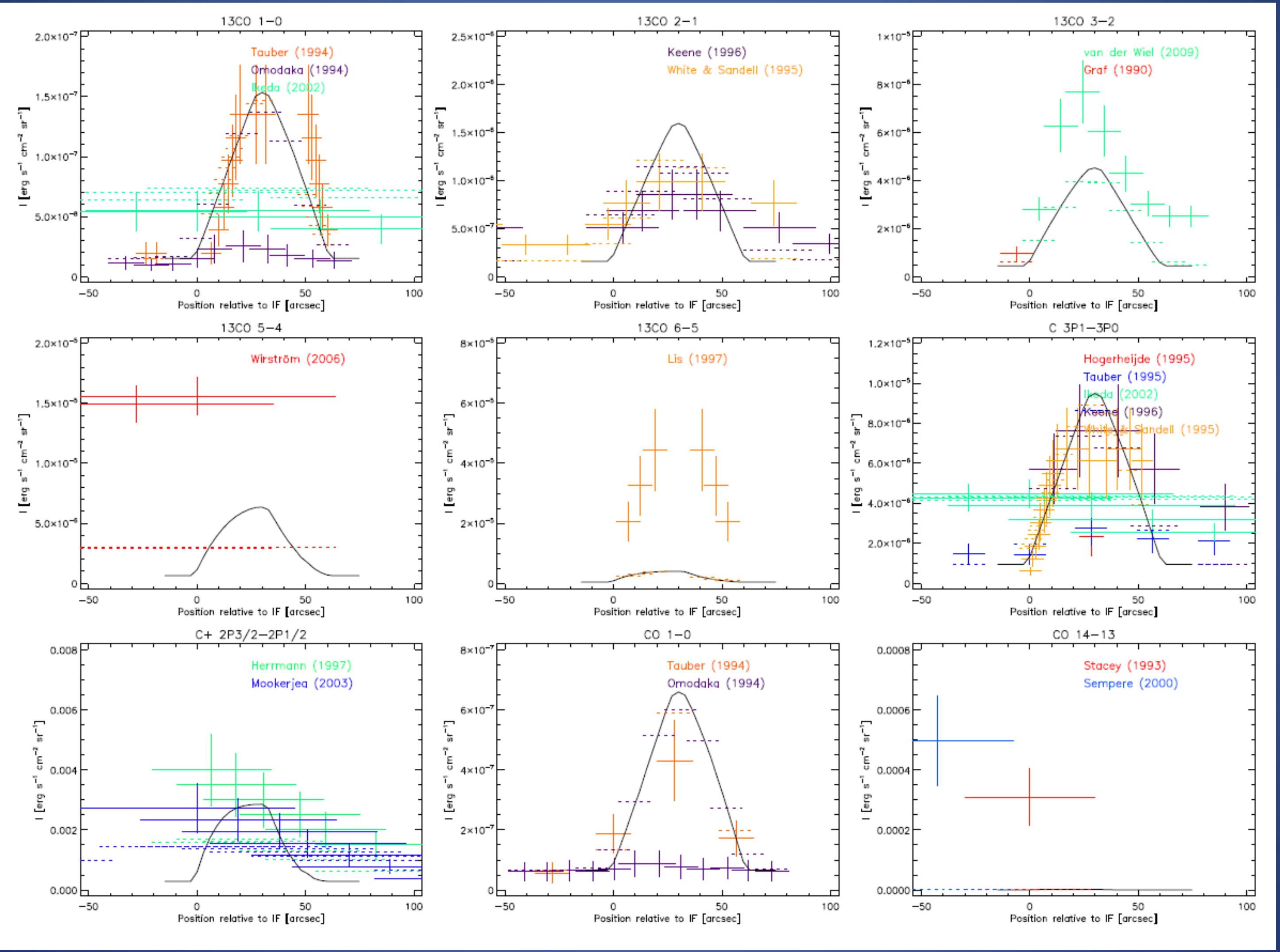


PhD thesis in progress:

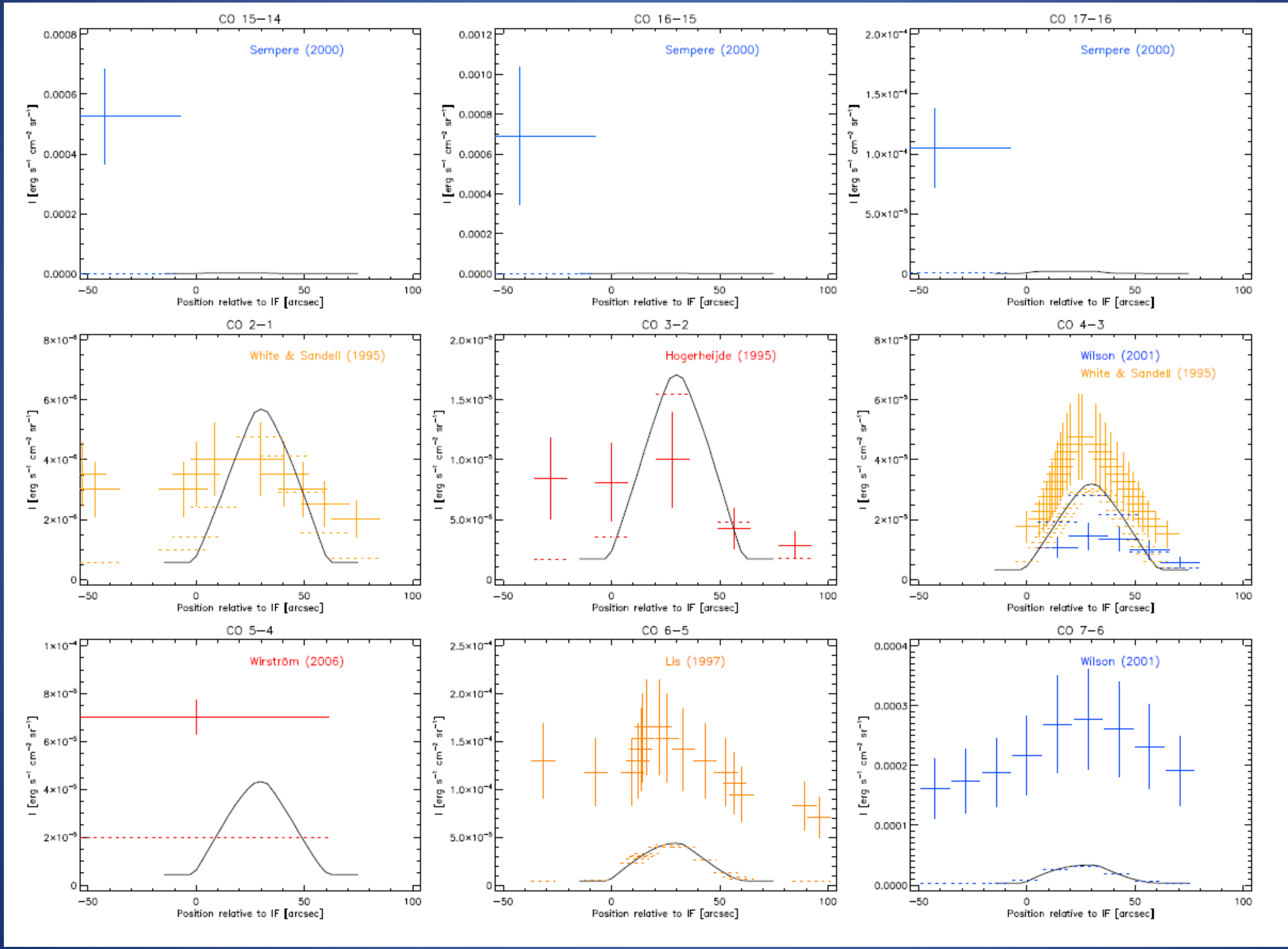
Modeling the intensity profile across the bar:

- assuming n layers of clumpy PDRs
- FUV is attenuated for subsequent layers
- E.g.: upper clump mass and mean clump density are fitted
- convolved with Gaussian beam

Across the bar



Across the bar



Summary

- The 2-phase clumpy model is able to perform a not too bad first fit to the Orion Bar data.
- A careful review of ALL available data is neccessary.
- Followed by a tuning/modification of the applied model atte.mpts to refine the analysis