Time-dependent chemical modeling of H/H_2 and $C^+/C/CO$ transitions in the Orion Bar

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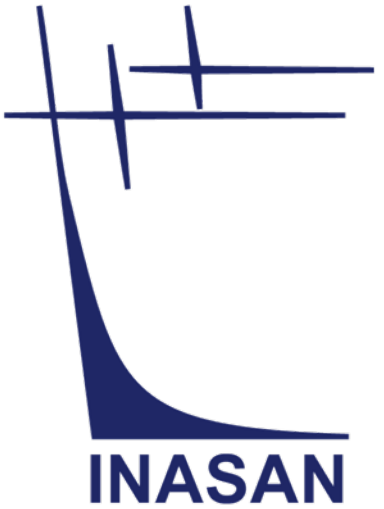
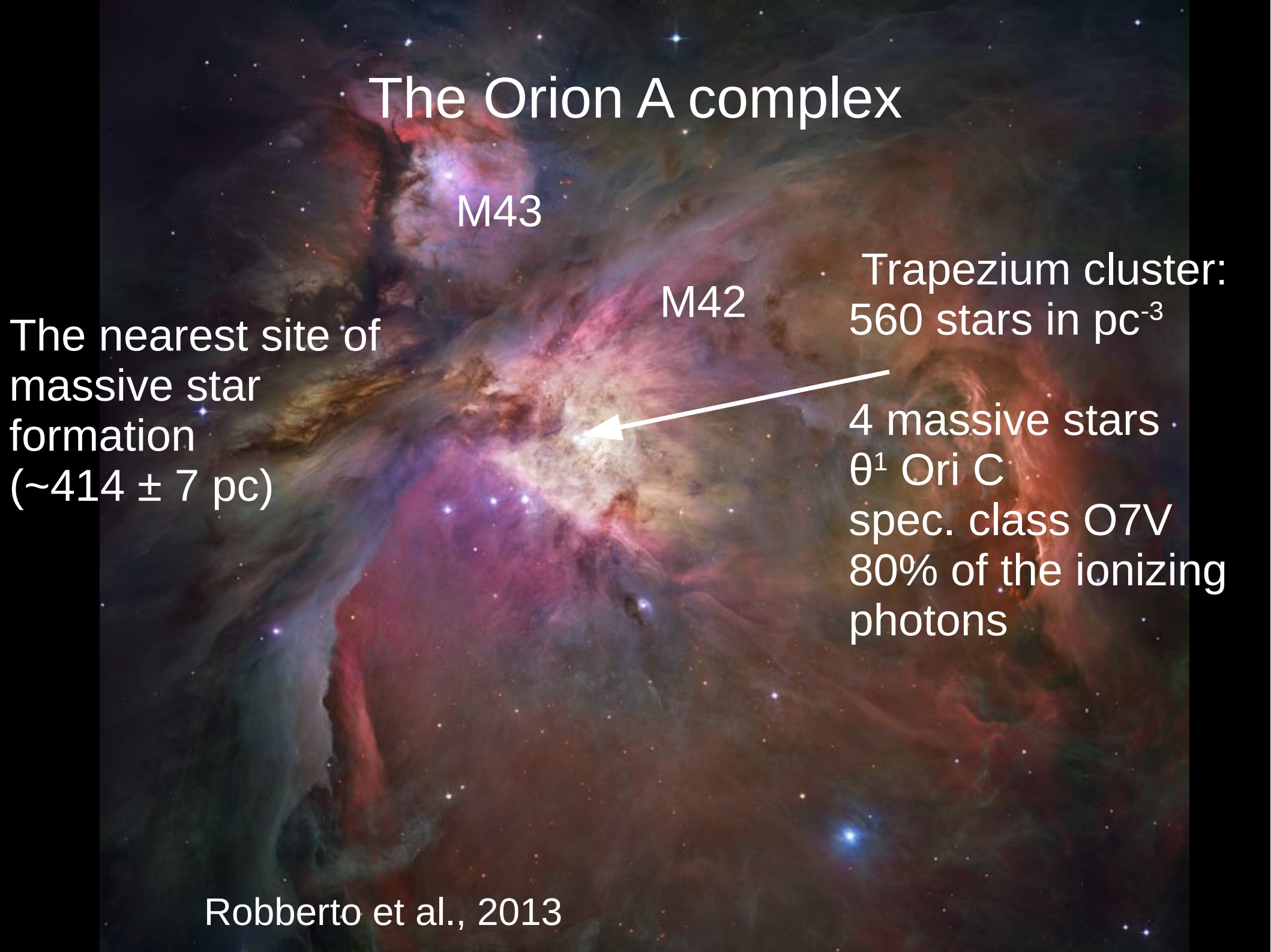
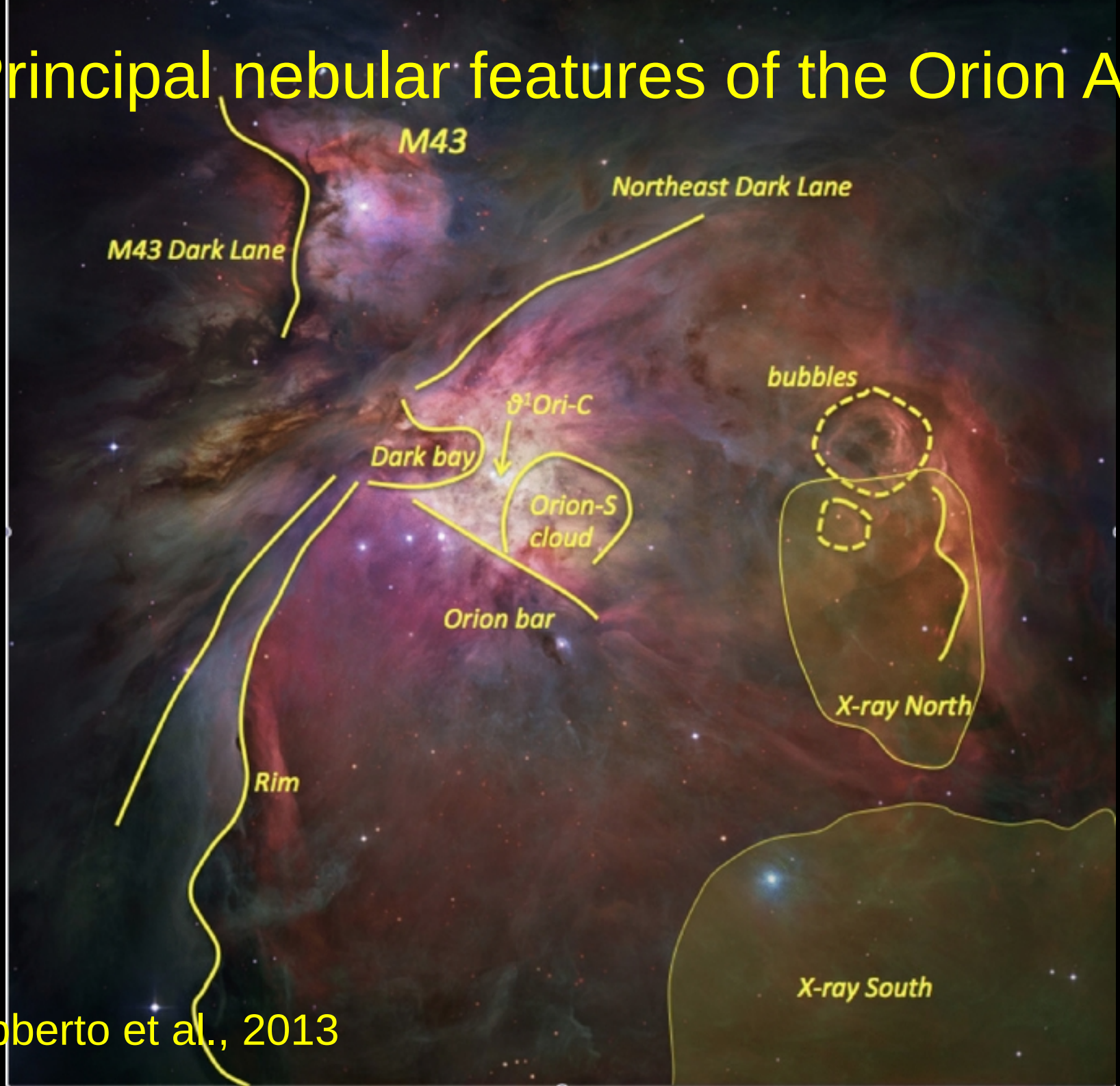


KIDA-2017, Sep 2017, Bordeaux


The Orion A complex
M43
M42
Trapezium cluster:
560 stars in pc-3
The nearest site of
massive star
formation
(~414 ± 7 pc)
4 massive stars
θ1 Ori C
spec. class O7V
80% of the ionizing
photons
Robberto et al., 2013

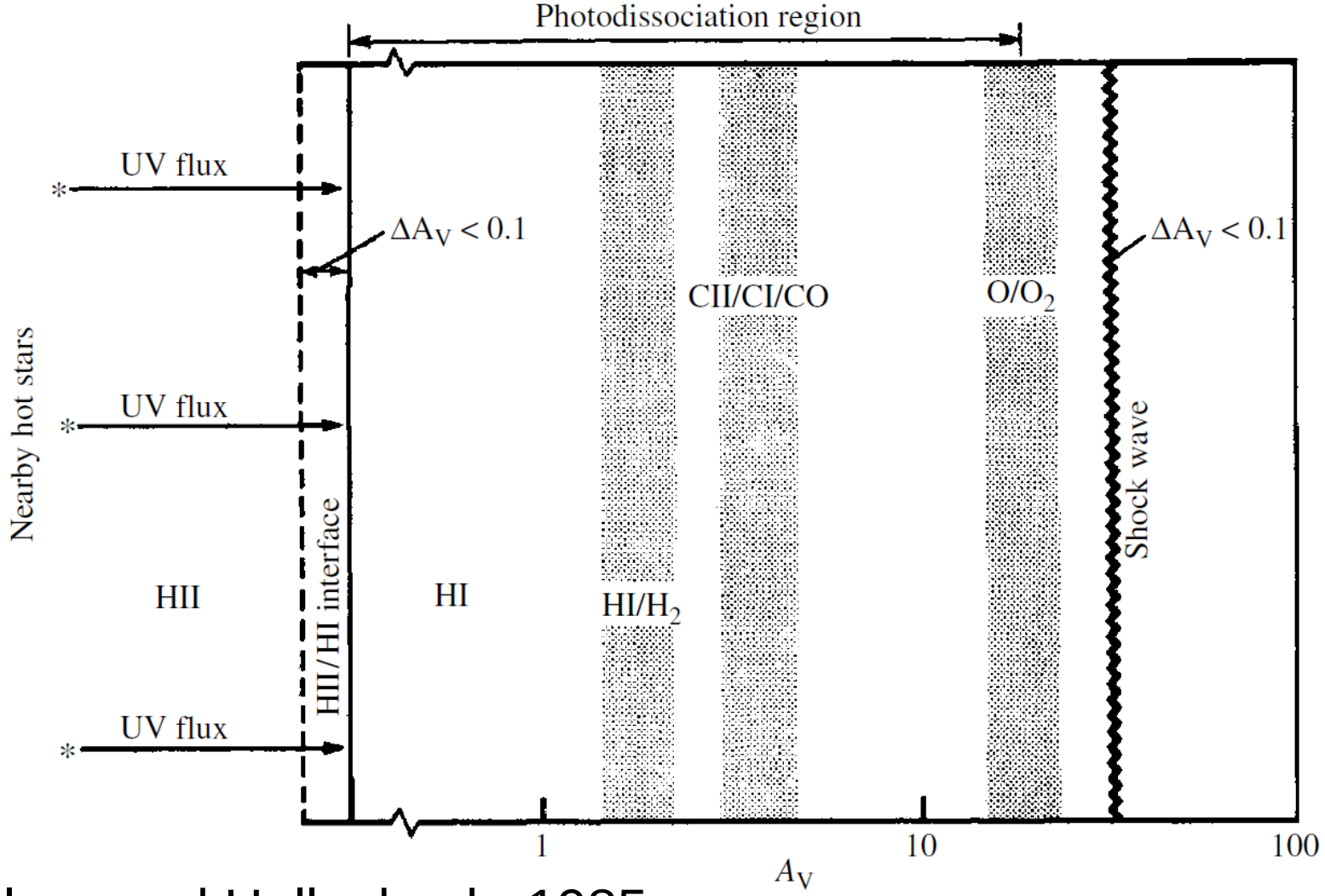
Principal nebular features of the Orion A



Robberto et al., 2013

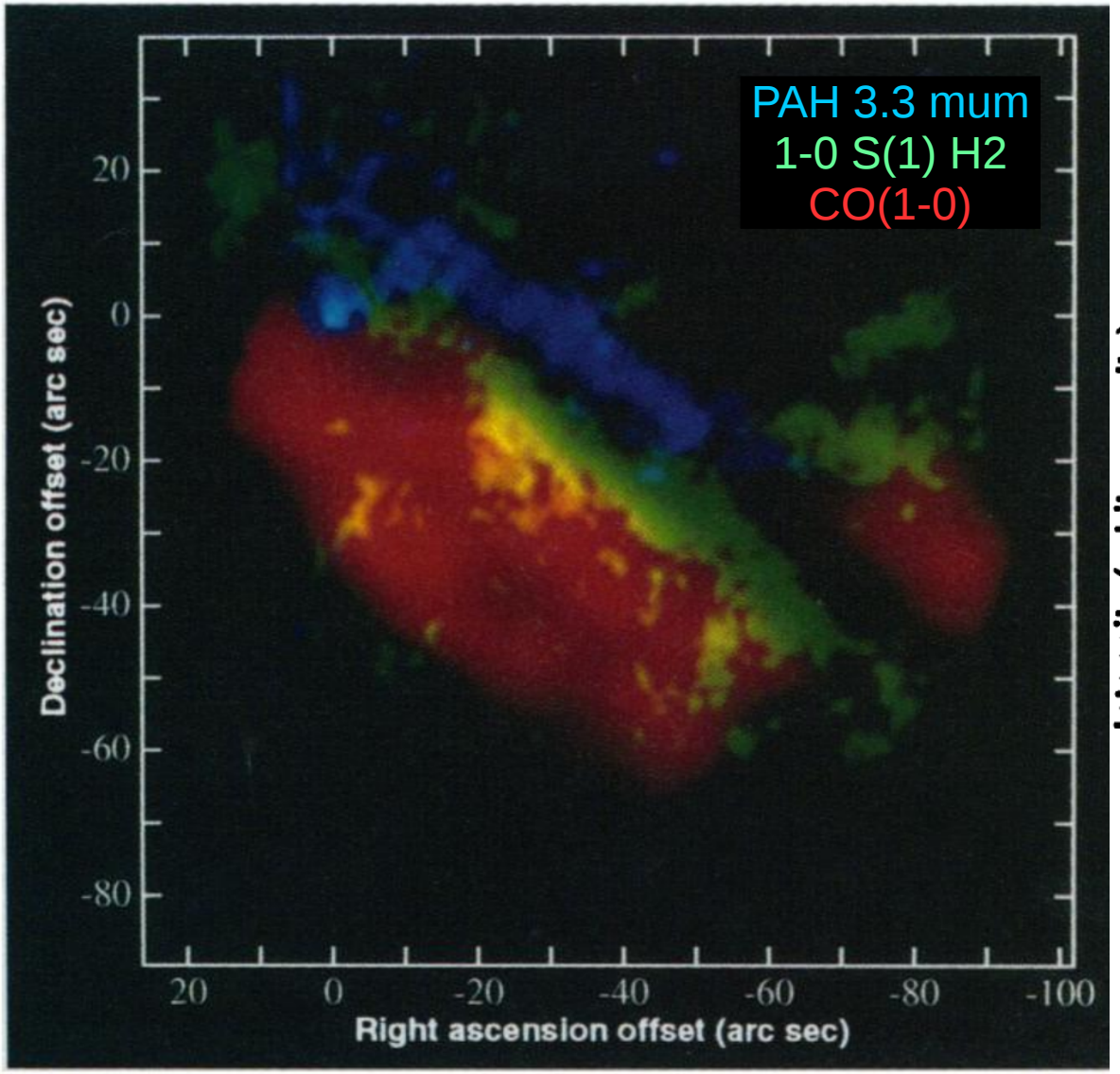
Basic model of photodissociation regions

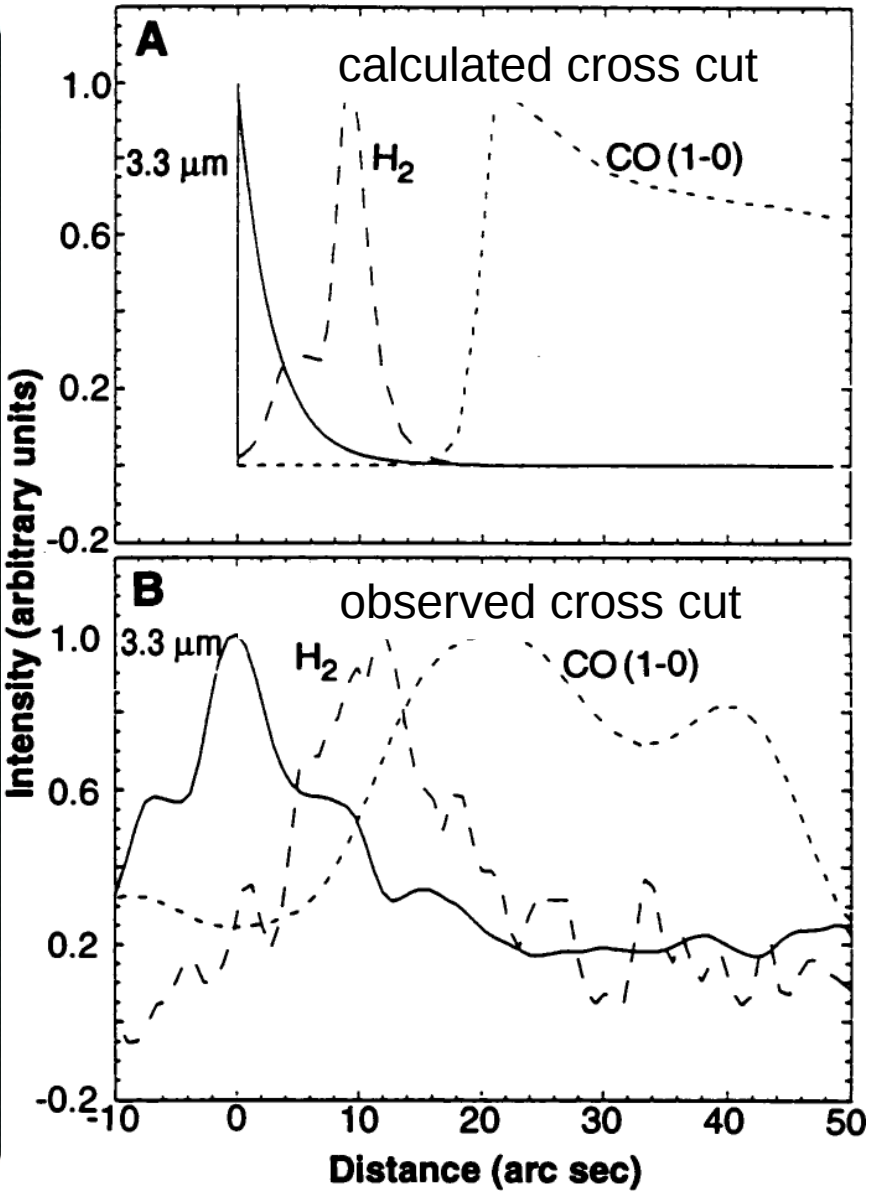
- Photodissociation regions are regions where FUV (6-13.6 eV) photons dominate the energy balance and/or chemistry.



Tielens and Hollenbach, 1985

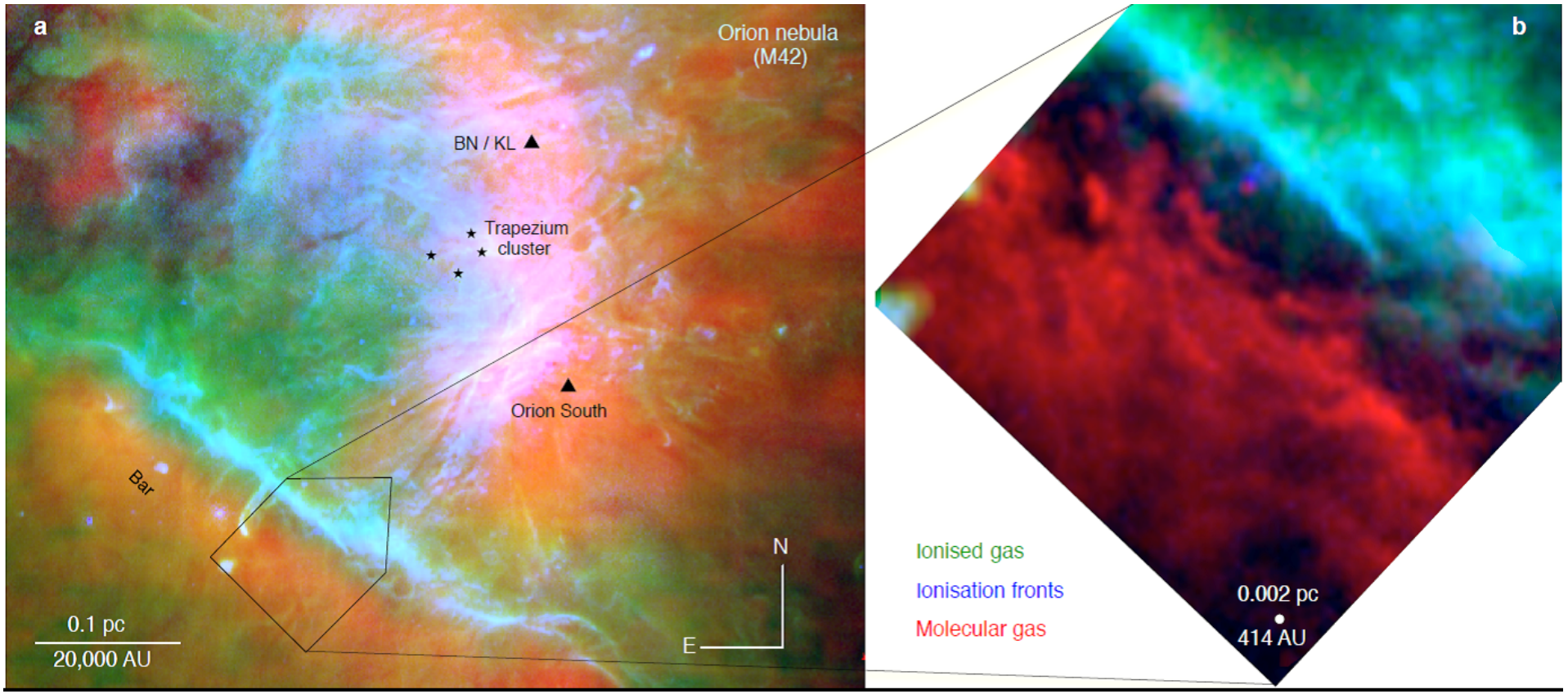
Success of the steady-state model





Tielens et al., 1993

New ALMA observations of HCO^+(4-3)



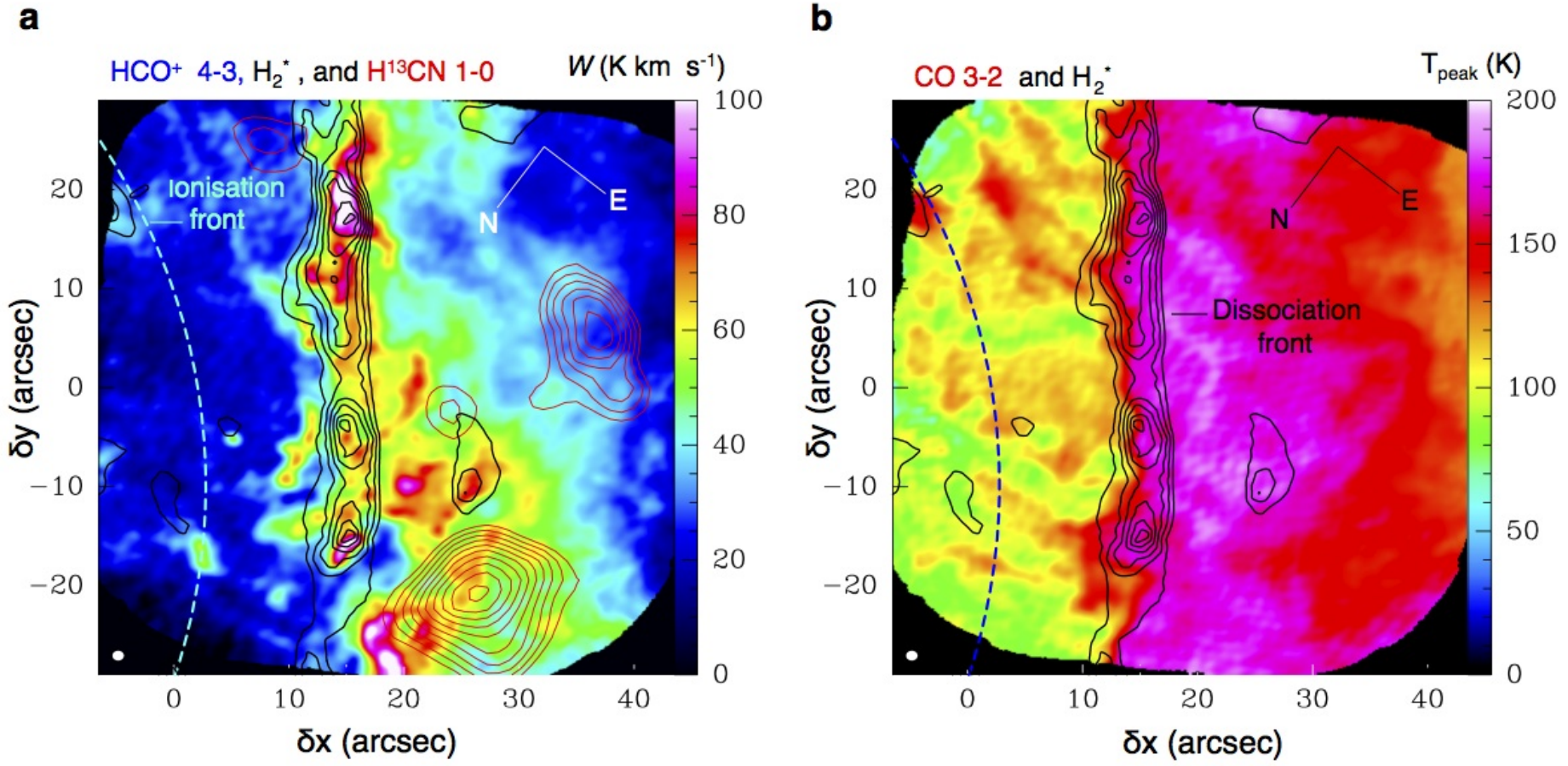
[SII] 6731 A

[OI] 6300 A

1" resolution HCO^+ (4-3)

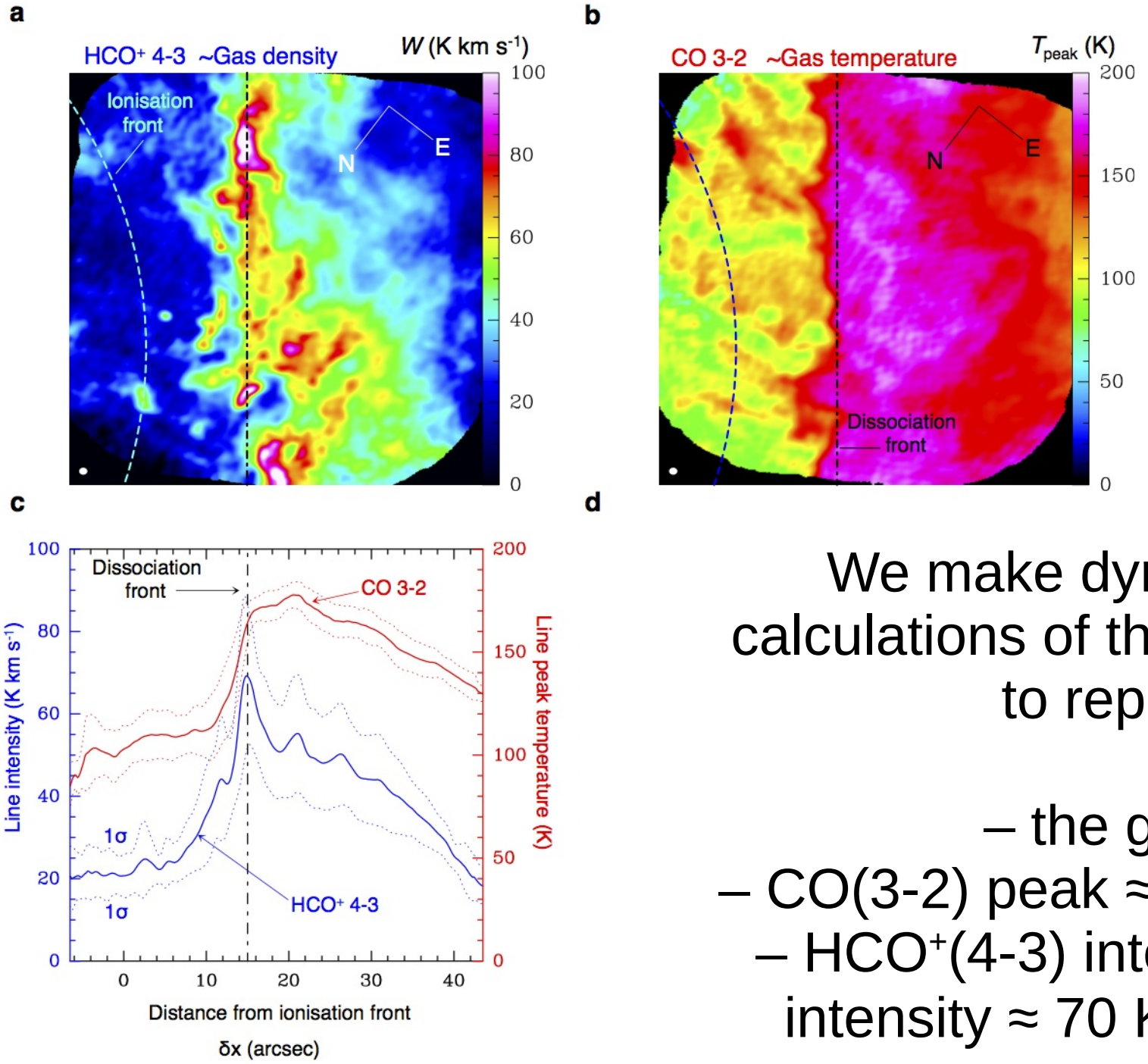
Goicoechea et al., 2016

Gap between H_2 and CO peak emission



H_2 and CO diss. fronts are closer to each other (5") compared to the equilibrium model predictions (10")

Goicoechea et al., 2016



We make dynamical calculations of the PDR to reproduce:

– the gap ≤ 5"
– CO(3-2) peak ≈ 160 K
– HCO^+(4-3) integrated intensity ≈ 70 K km s^{-1}

Goicoechea et al., 2016

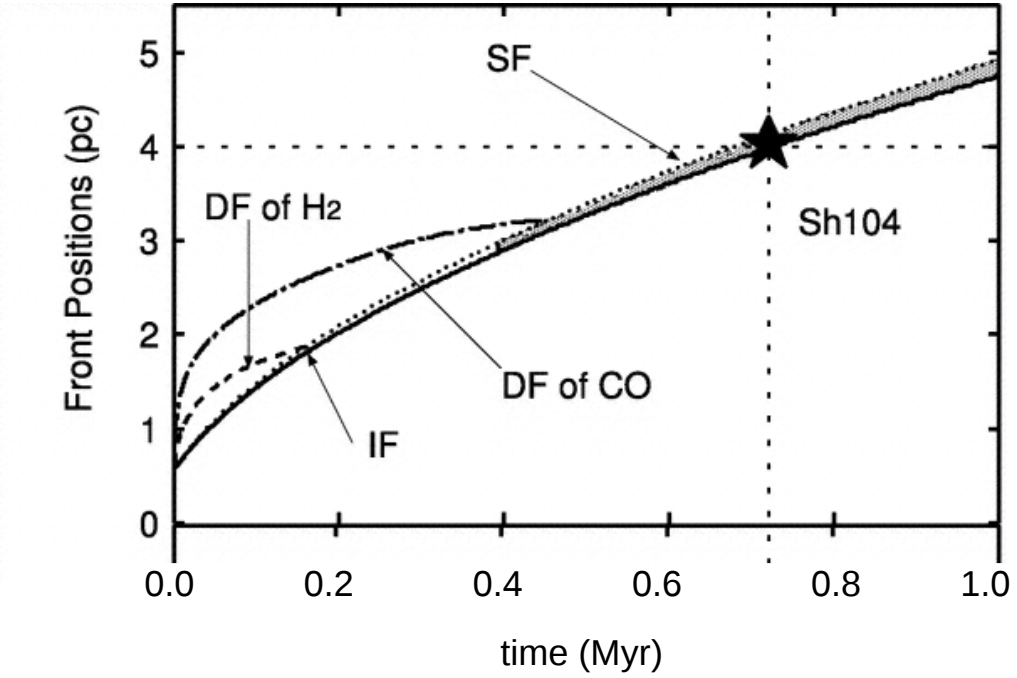
Dynamical PDR models

Storzer & Hollenbach, 1998, analytical approach:

– $C^+/C/CO$ transition layer is closer to the dissociation front (DF) of H_2 compared to the equilibrium model

– nonequilibrium effects in the Orion Bar are probably small

Hosokawa & Inutsuka, 2005:



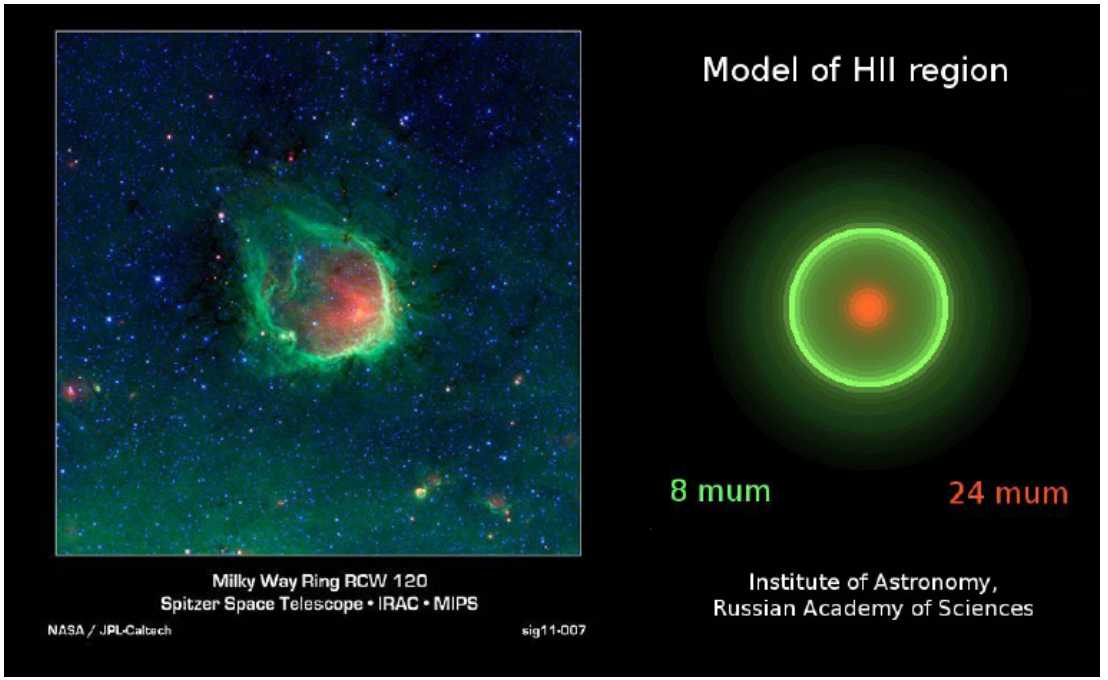
1D numerical model of an expanding HII region

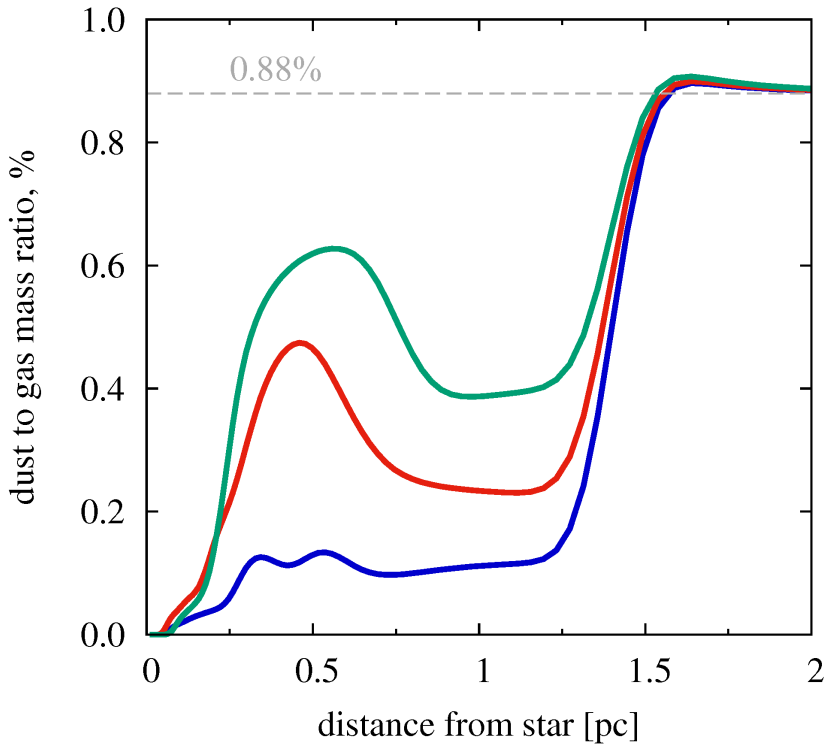
MARION code

- 1D gas dynamics based on the ZEUS-2D code (Stone&Norman, 2002)
- dynamics of charged dust, dust size distribution
- ionization, dissociation, gas phase chemistry + accretion and desorption
- essential heating and cooling processes

Kirsanova et al., 2009
Pavlyuchenkov et al., 2013
Akimkin et al., 2015
Akimkin et al., 2017

MARION code: study of dust and PAHs dynamics in expanding HII regions





Kirsanova et al., 2009
Pavlyuchenkov et al., 2013
Akimkin et al., 2015
Akimkin et al., 2017

Model setup

plane-parallel slab

only gas-phase chemistry

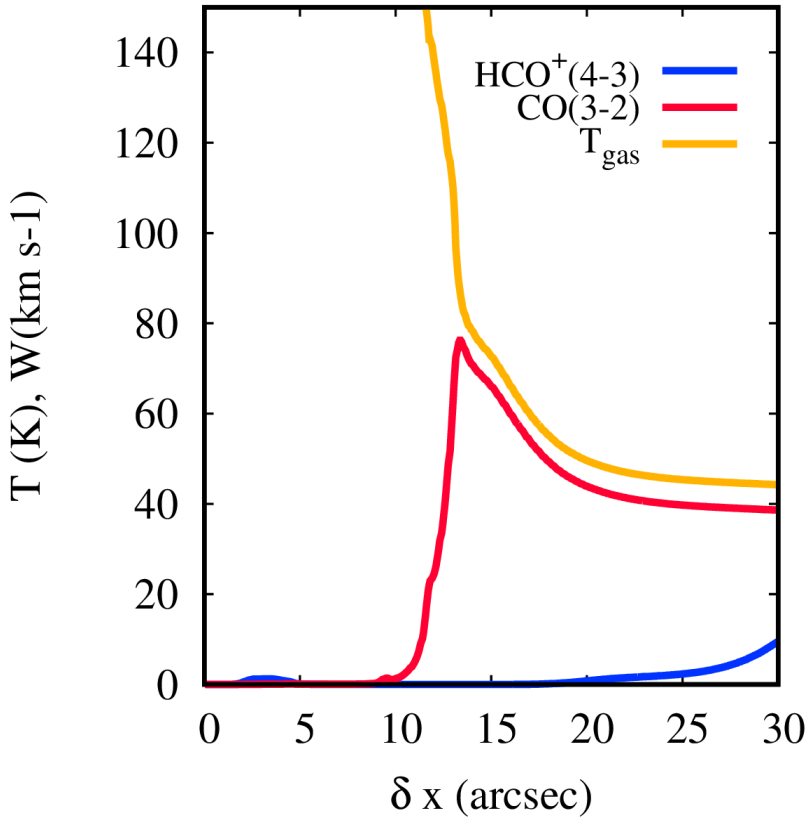
chemical network from the PDR benchmarking workshop (Rollig et al., 2007) + photo-reactions cross-sections from the Leiden photo site (van Dishoeck et al, 2006)

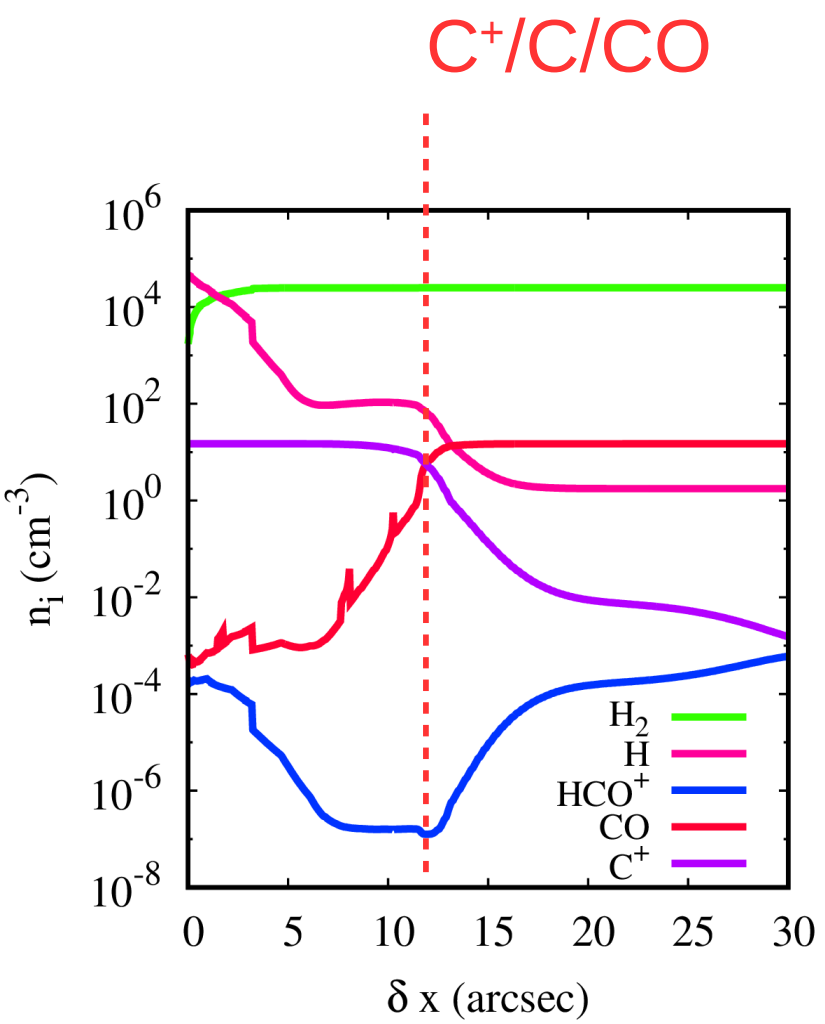
31 species: H, H^+, H_2, H_2^+, H_3^+, O, O^+, OH^+, OH, O_2, O_2^+, H_2O, H_2O^+, H_3O^+, C, C^+, CH, CH^+, CH_2, CH_2^+, CH_3, CH_3^+, CH_4, CH_4^+, CH_5^+, CO, CO^+, HCO^+, He, He^+, e^-

energy intensity of the Draine field χ at surface	4×10^4
n_{gas}	5×10^4 cm^{-3}
T_{gas}	10K
dust model	MRN WD07 R_V=3.1 WD16 R_V=5.5
H_2	0.5
He	0.1
CO	3×10^{-4}
O_2	5×10^{-5}

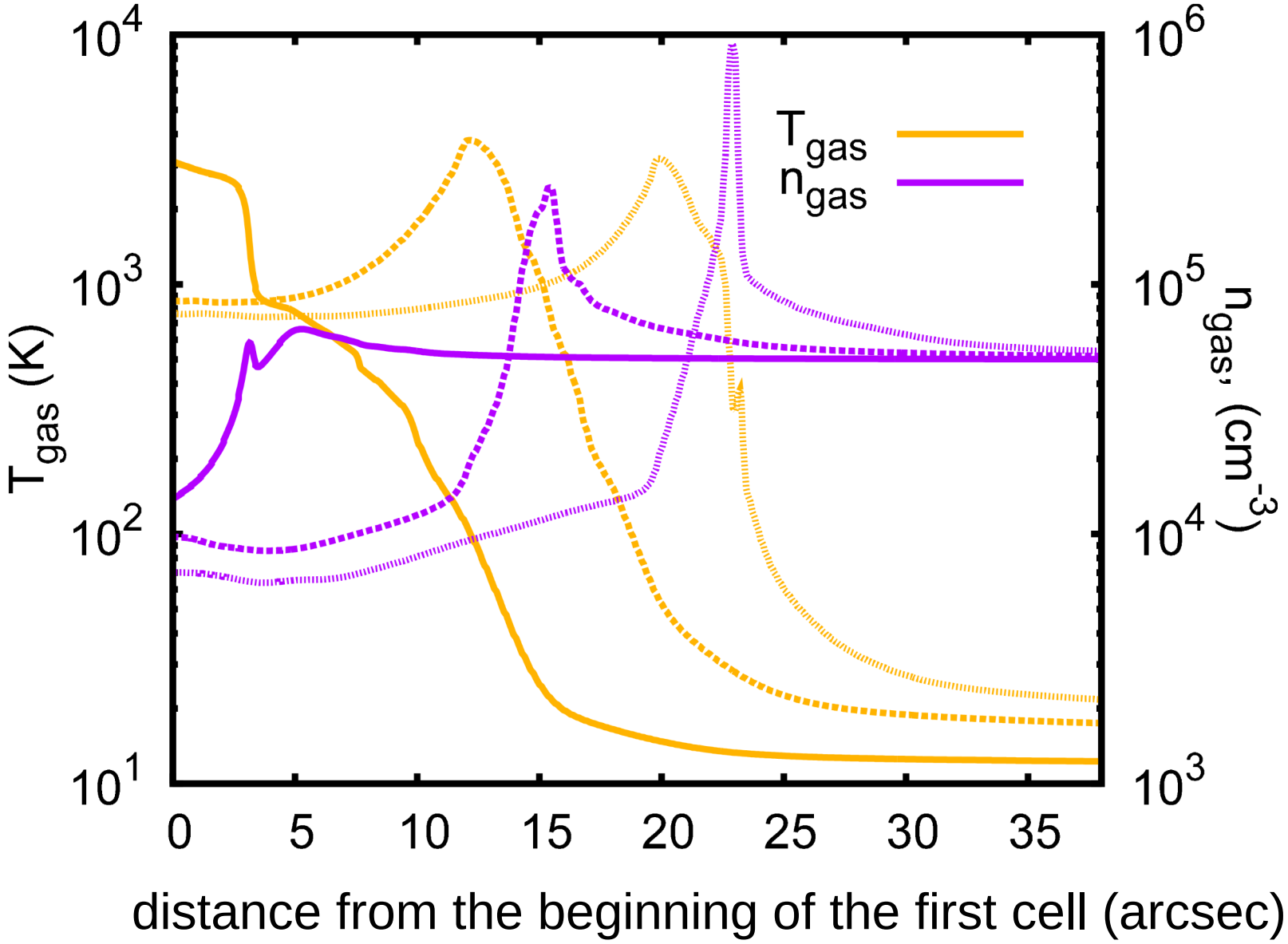
Static model

- RADEX setup: T_{bg} = 2.7K
- linewidth = 2 km s^{-1}
- line of sight depth = 0.12 pc

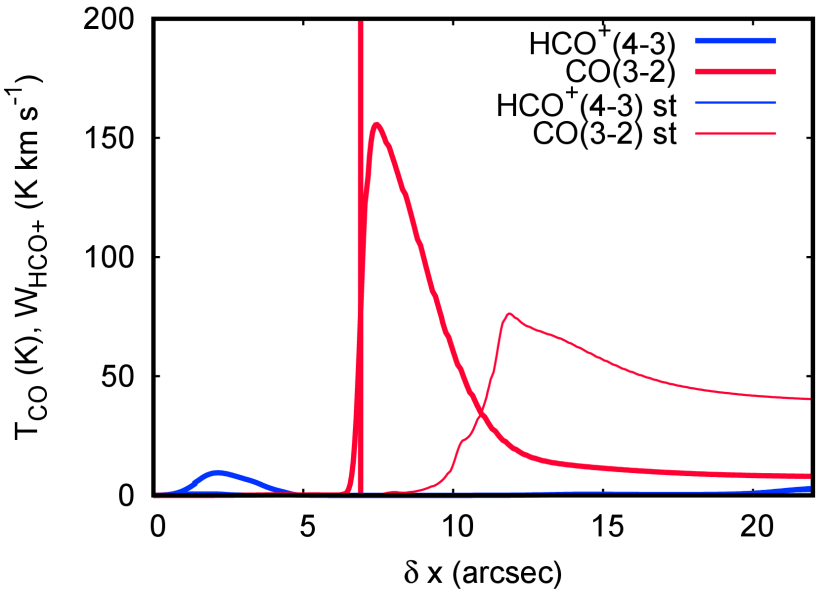


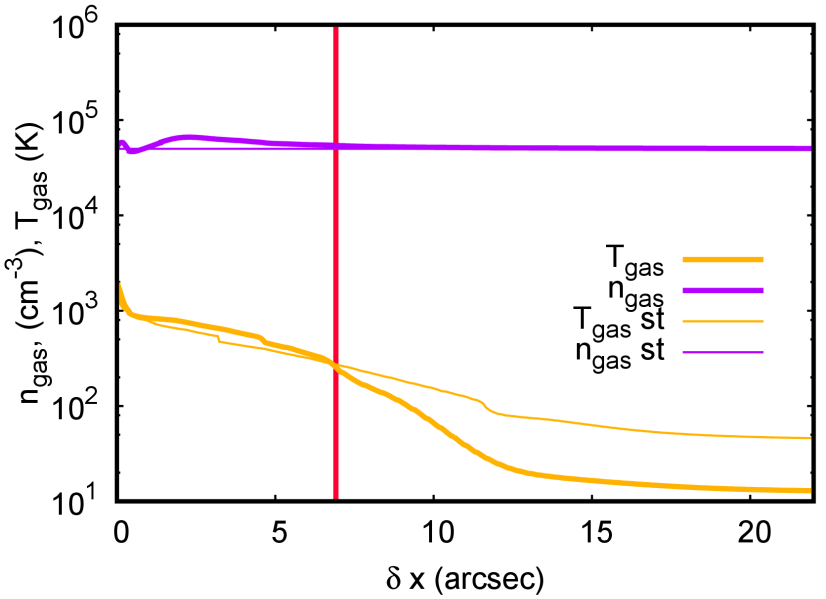


Dynamical model: 3 moments of time



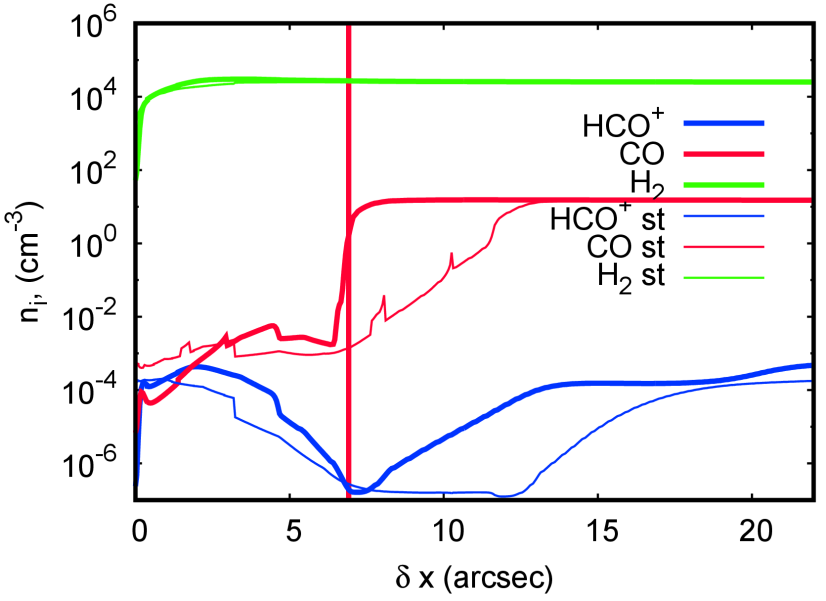
Dynamical model – moment 1



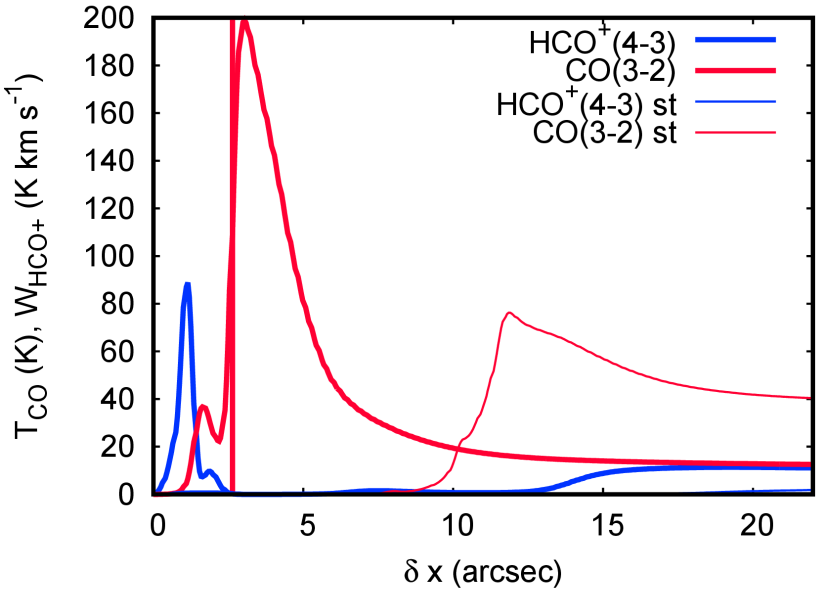


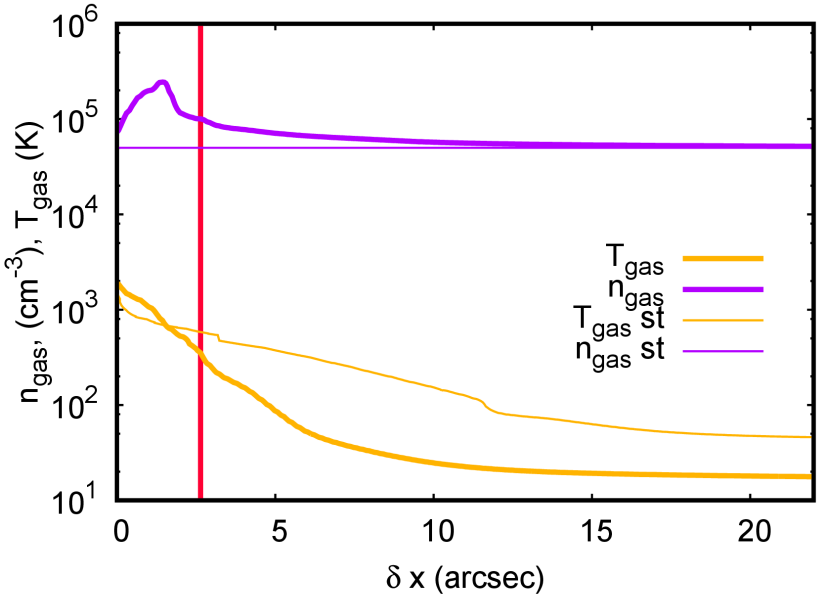
MRN

- t=1000 years
- the gap ≈ 5''



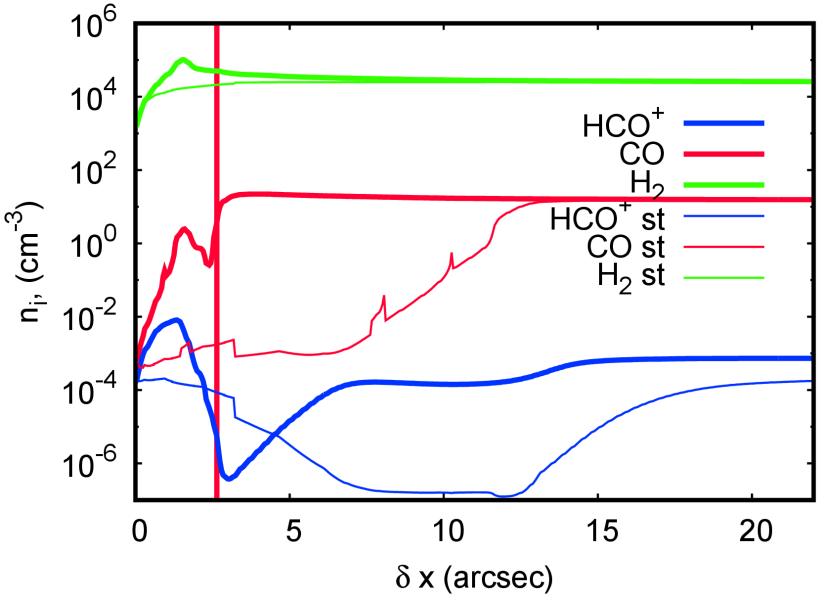
Dynamical model – moment 2



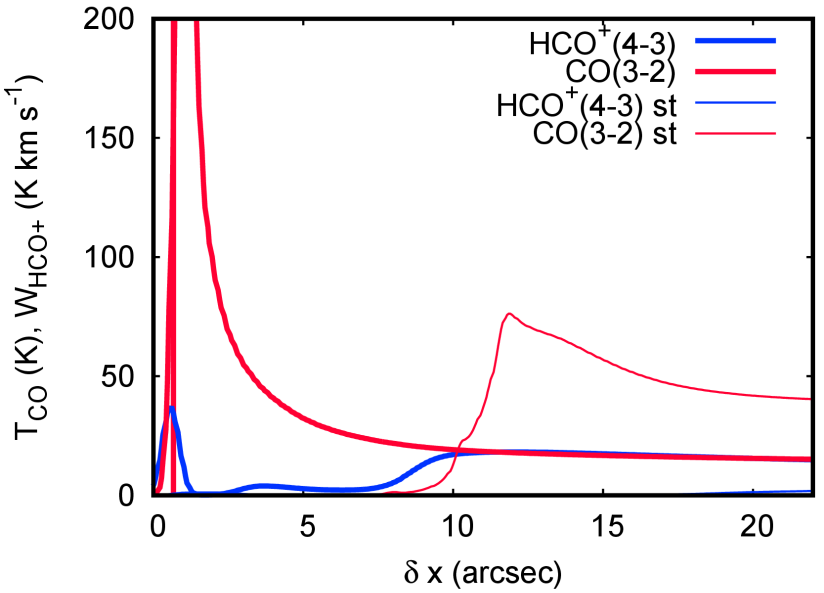


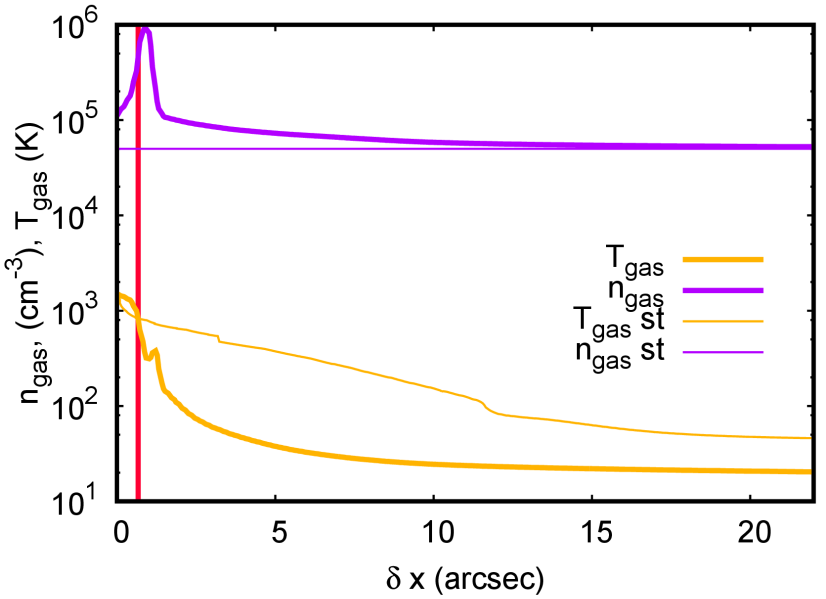
MRN

- t=2900 years
- the gap ≈ 2''



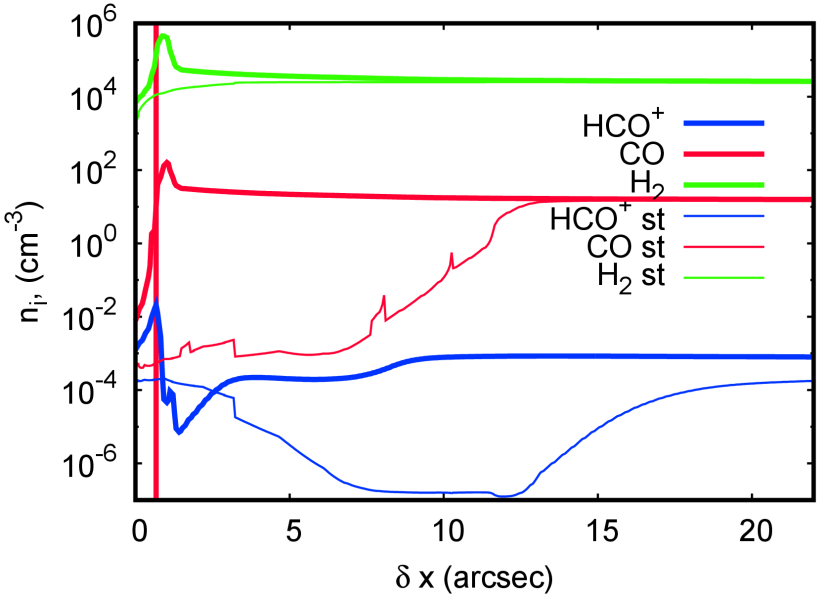
Dynamical model – moment 3



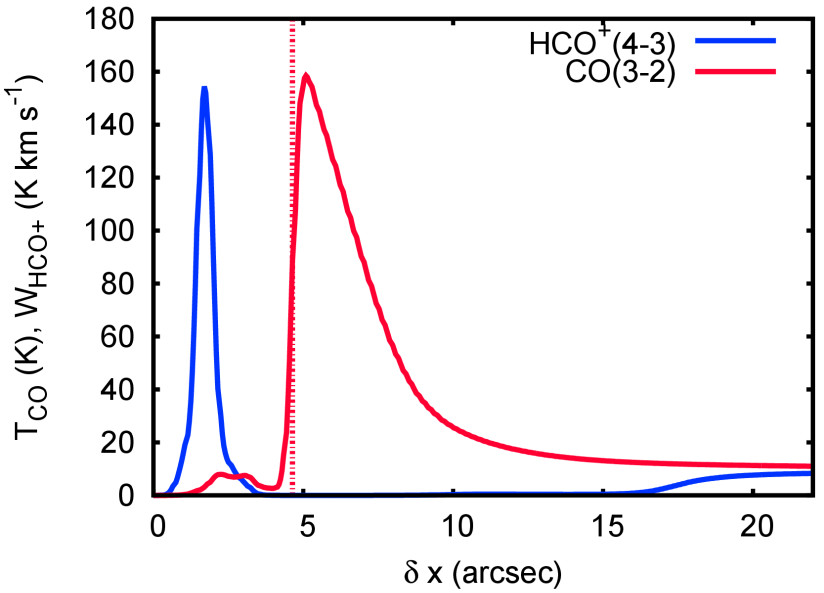


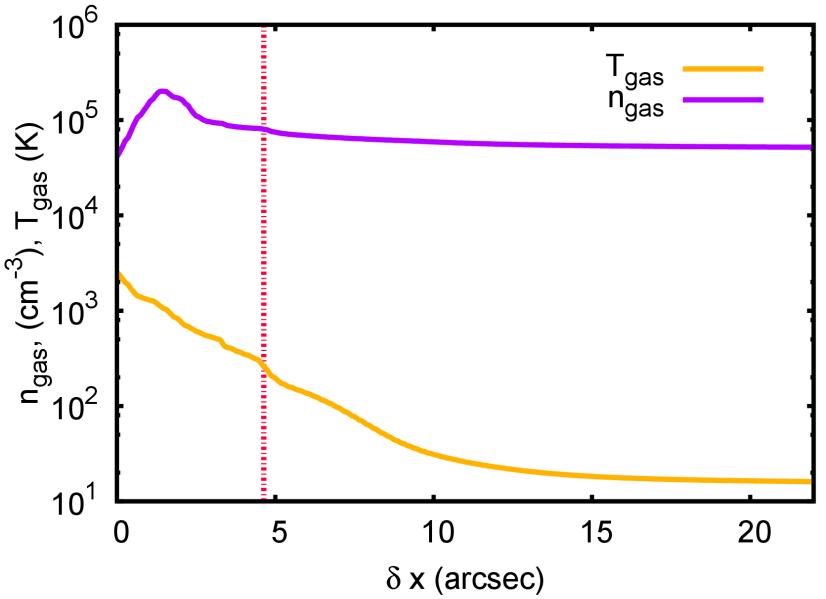
MRN

- t=2900 years
- the gap ≈ 1"



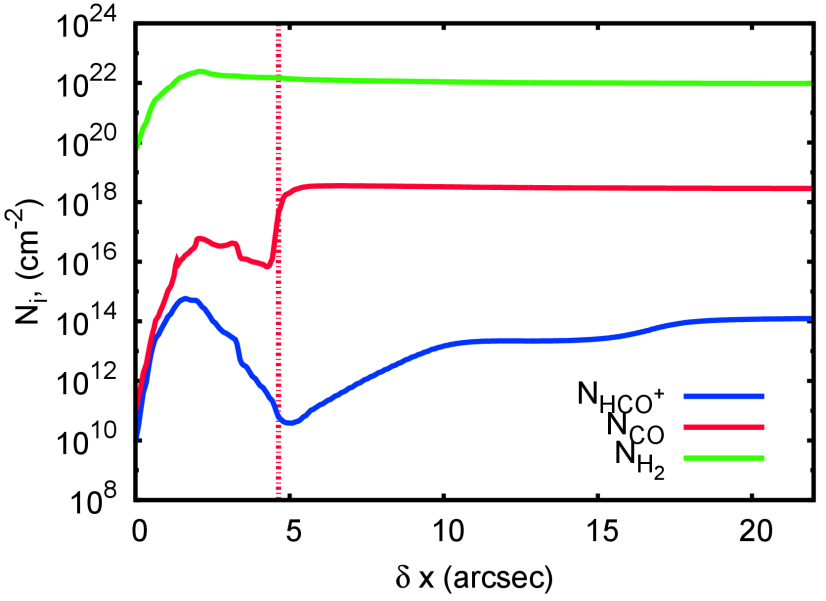
WD 07 model with Rv=3.1: even brighter HCO^+(4-3) emission



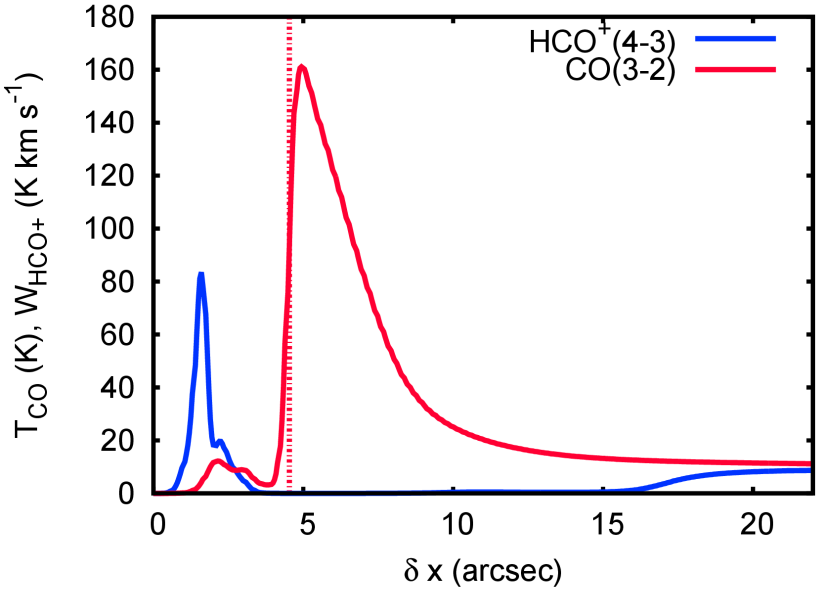


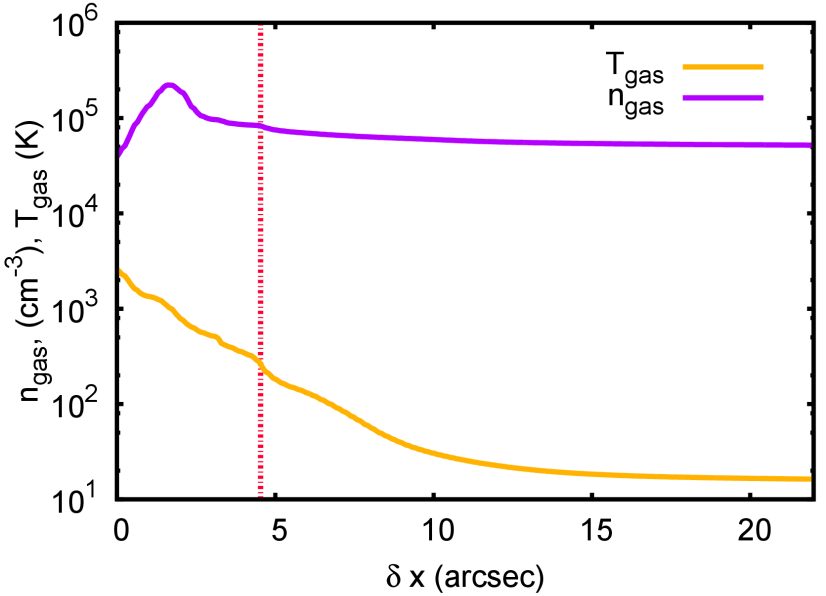
WD07

- t=2900 years
- the gap ≈ 4"



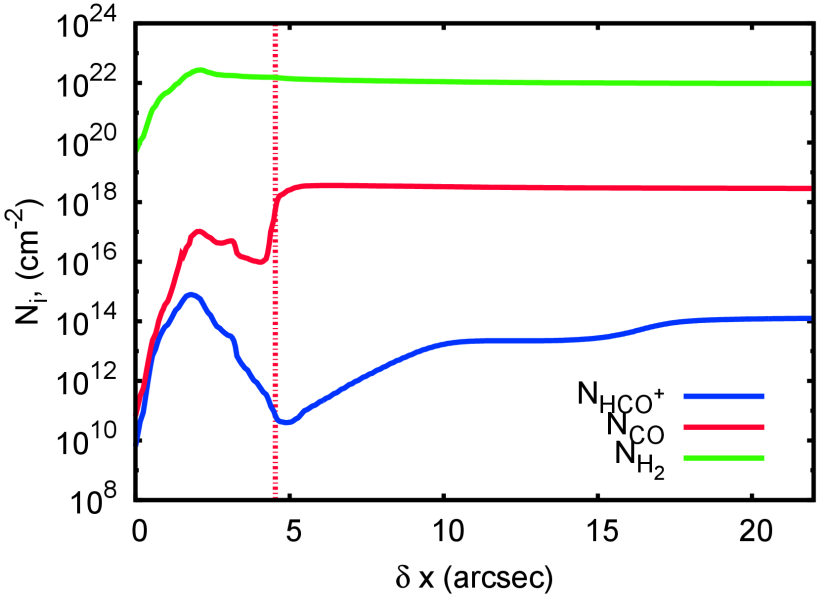
WD07 model with Rv=3.1: good agreement with observations



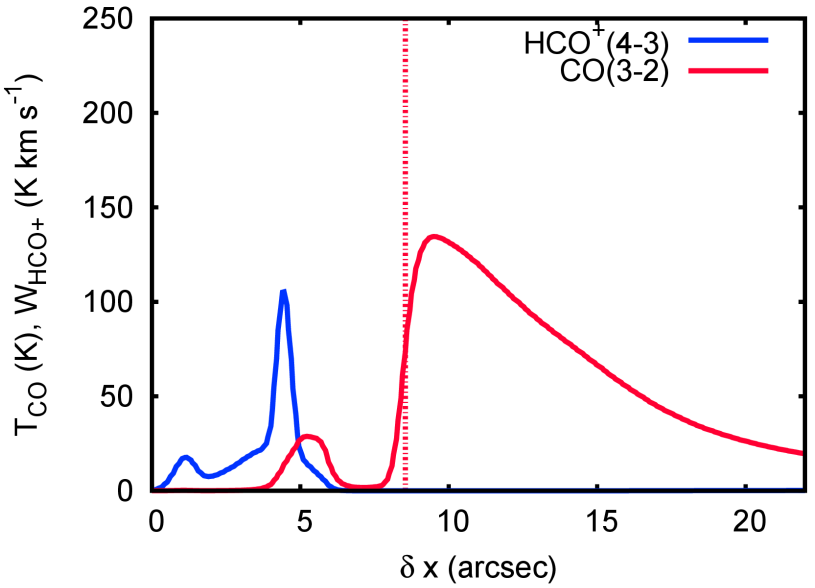


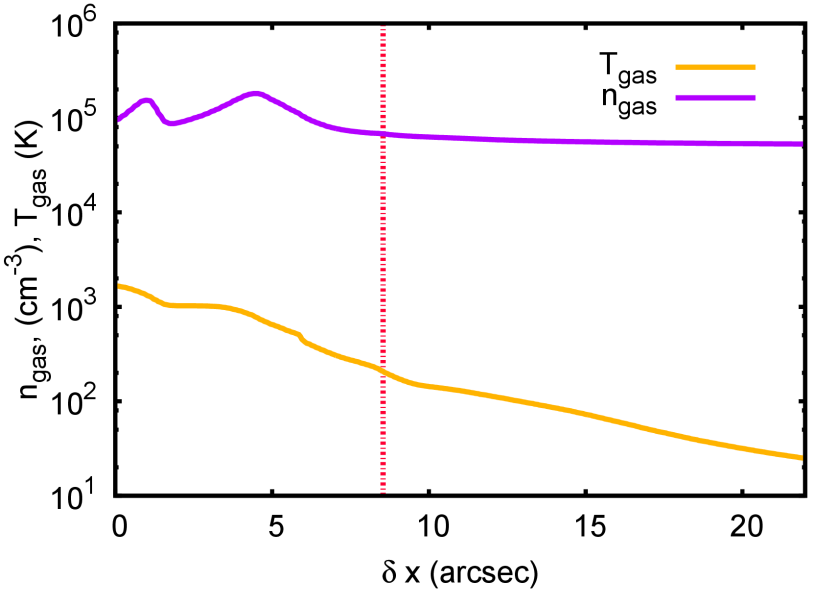
WD07

- t=3000 years
- the gap ≈ 4"



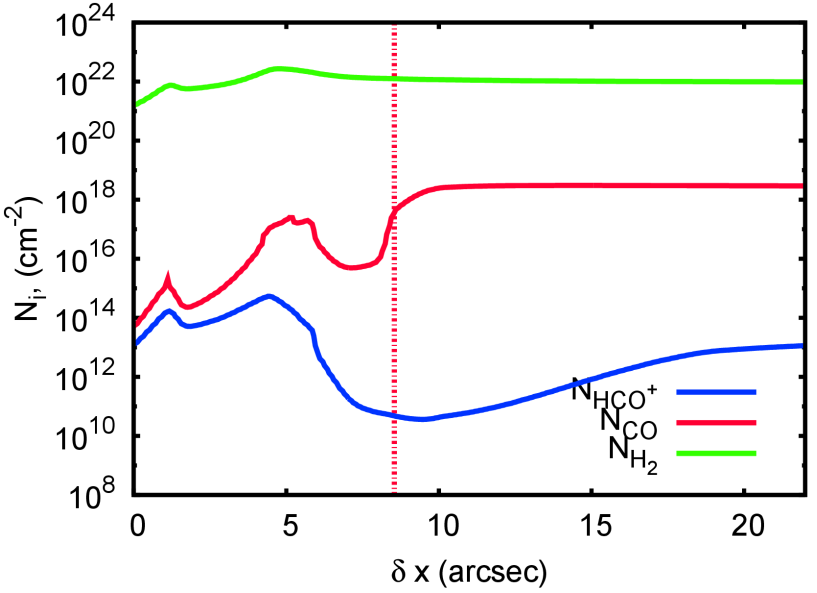
WD16 model with Rv=5.5: brighter HCO^+(4-3)



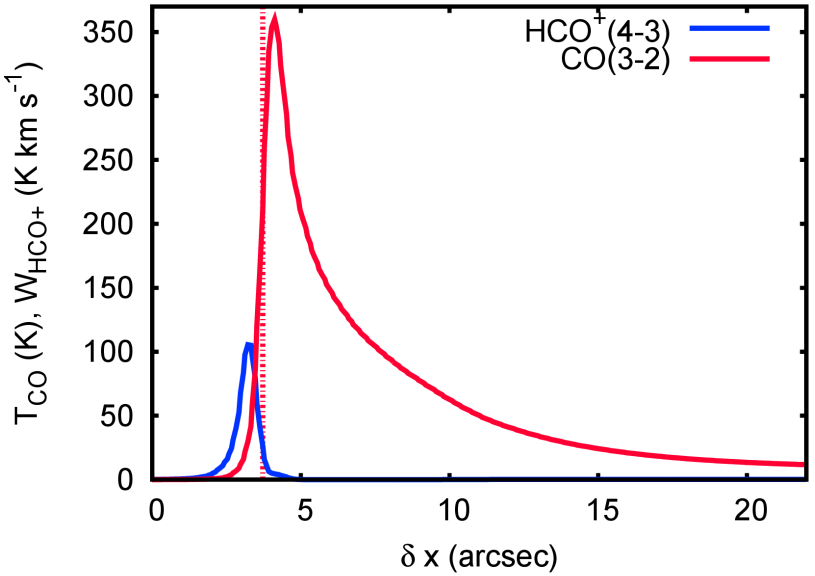


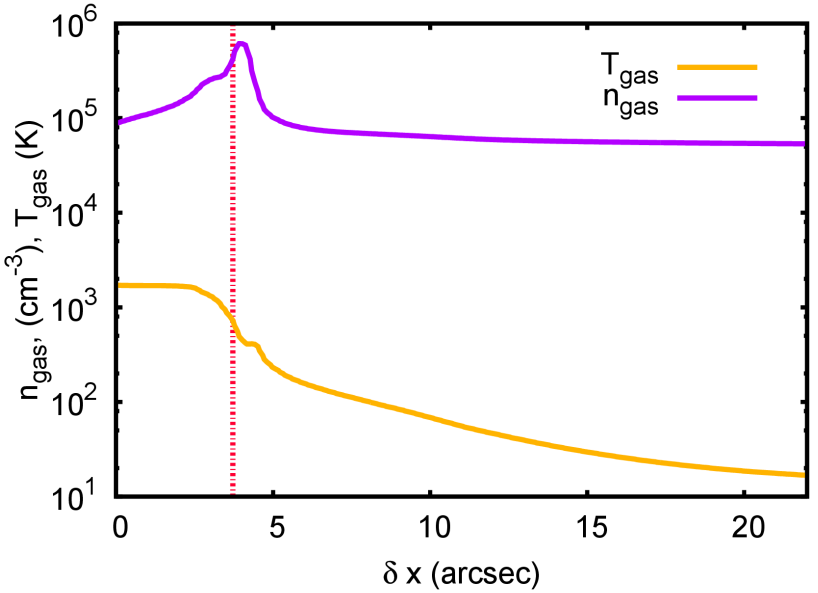
WD16

- t=4600 years
- the gap ≈ 5", but H_2 and CO DF are too far away ≈ 8"
- HCO^+(4-3) is brighter than with WD07 and MRN dust



WD 16 model with Rv=5.5: brighter HCO^+(4-3) and CO(3-2)

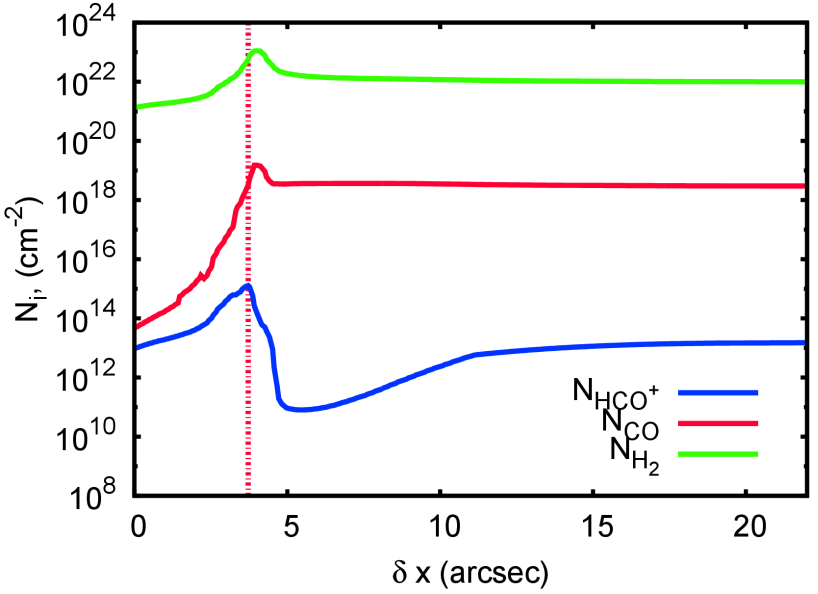




WD16

- t=6300 years
- the gap ≈ 1"

HCO^+(4-3) and CO(3-2) are brighter than with WD07 and MRN dust and than in observations



Conclusion

- Using MARION model we reproduce ALMA observations of CO(3-2) and HCO^+(4-3) in the Orion Bar:
  - the gap between HCO^+(4-3) and CO(3-2) peaks ≈ 4''
  - CO(3-2) peak intensity ≈ 160 K
  - HCO^+(4-3) integrated intensity ≈ 70 K km s^{-1}
- bright HCO^+(4-3) appears just beyond the H_2 dissociation front toward the density enhancement.