2nd NCAC Symposium
*"The Orion Nebula: A Laboratory for the Study of Star Formation and Gaseous Nebulae"*

# Effects of Herbig-Haro objects and bars on the oxygen abundance in the Orion Nebula

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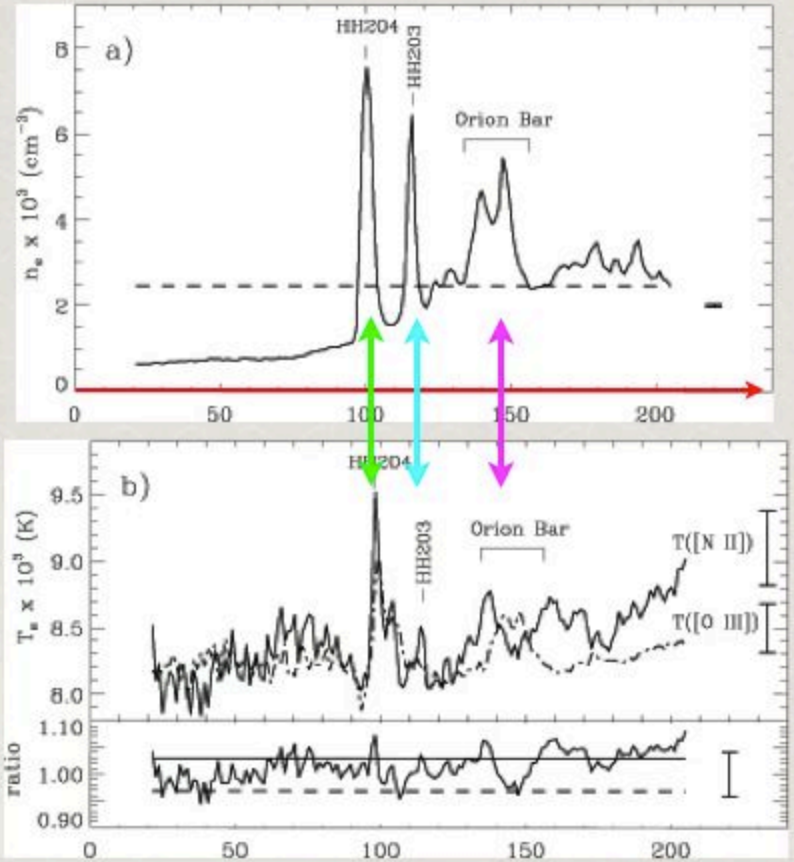
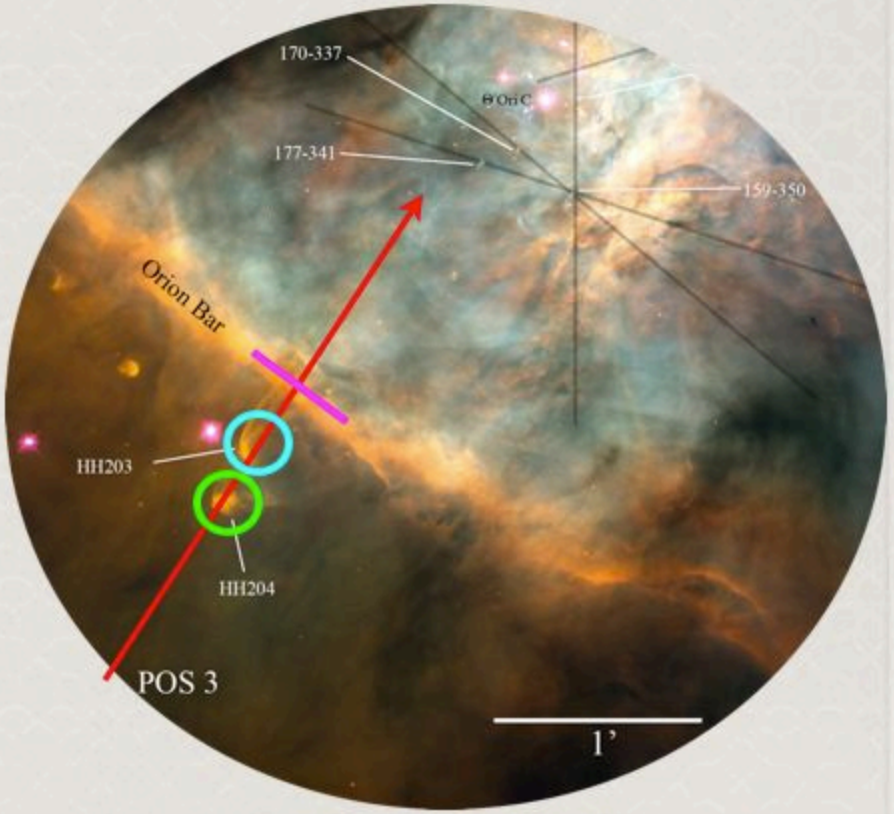
# Motivation

- The Orion Nebula: nearest and brightest Galactic HII region.
- Evidences of small-spatial scale variations (e.g. *Pogge et al. 1992; O'Dell et al. 2003; Rubin et al. 2003; Mesa-Delgado et al. 2008*).
- Related with morphological structures.

# Motivation

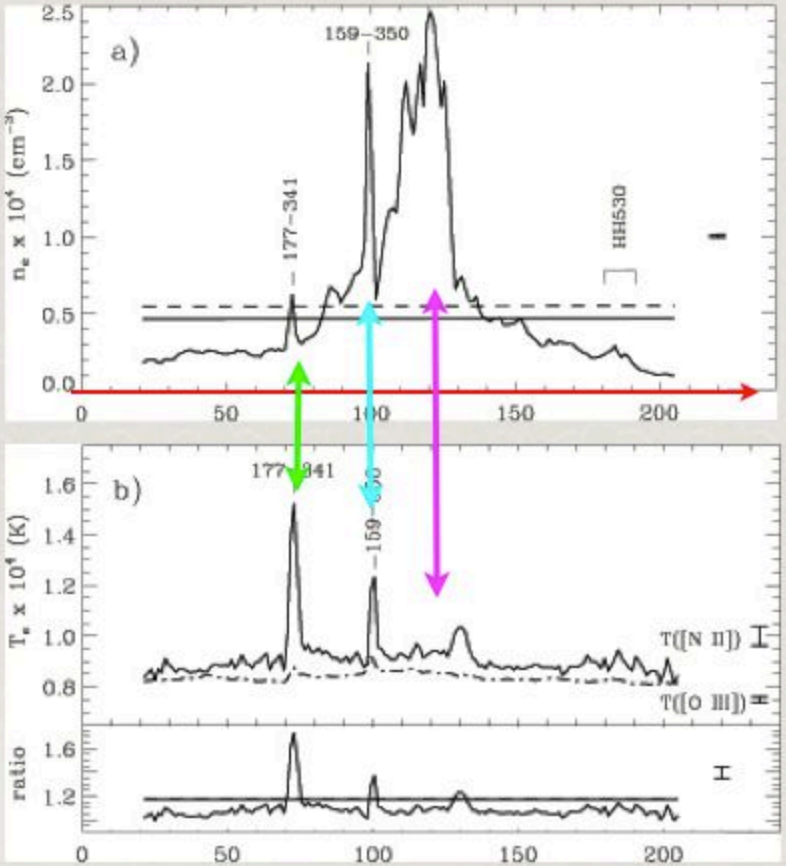
- Long-slit study (*Mesa-Delgado et al. 2008*)

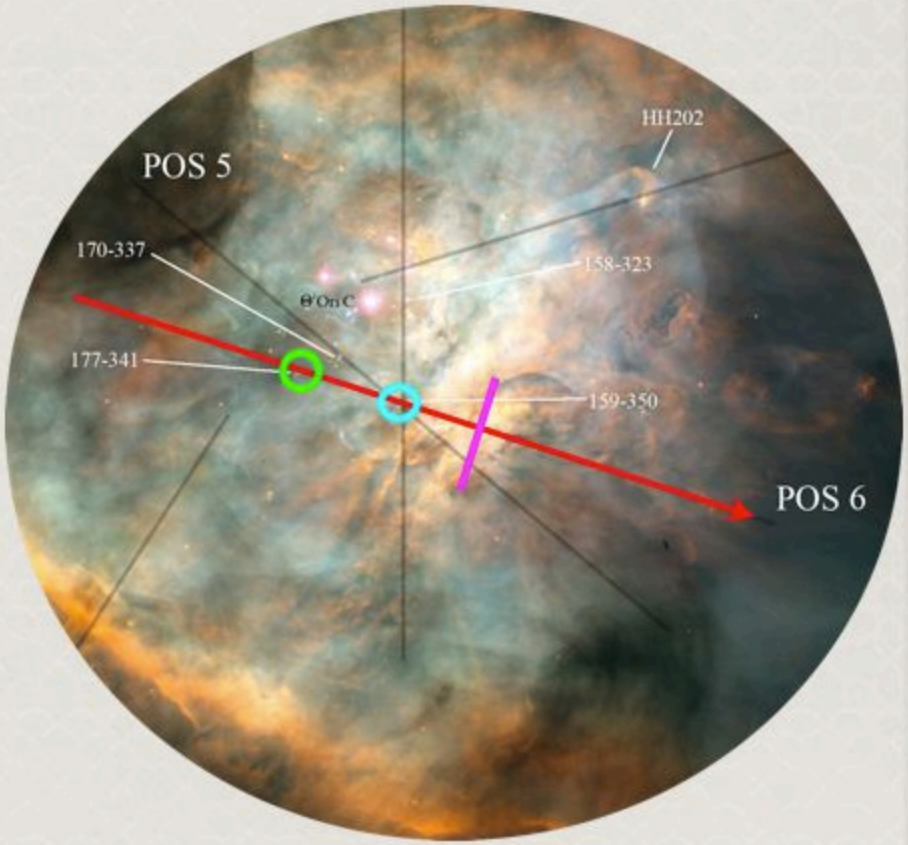


# Motivation

- Long-slit study (*Mesa-Delgado et al. 2008*)



# Motivation

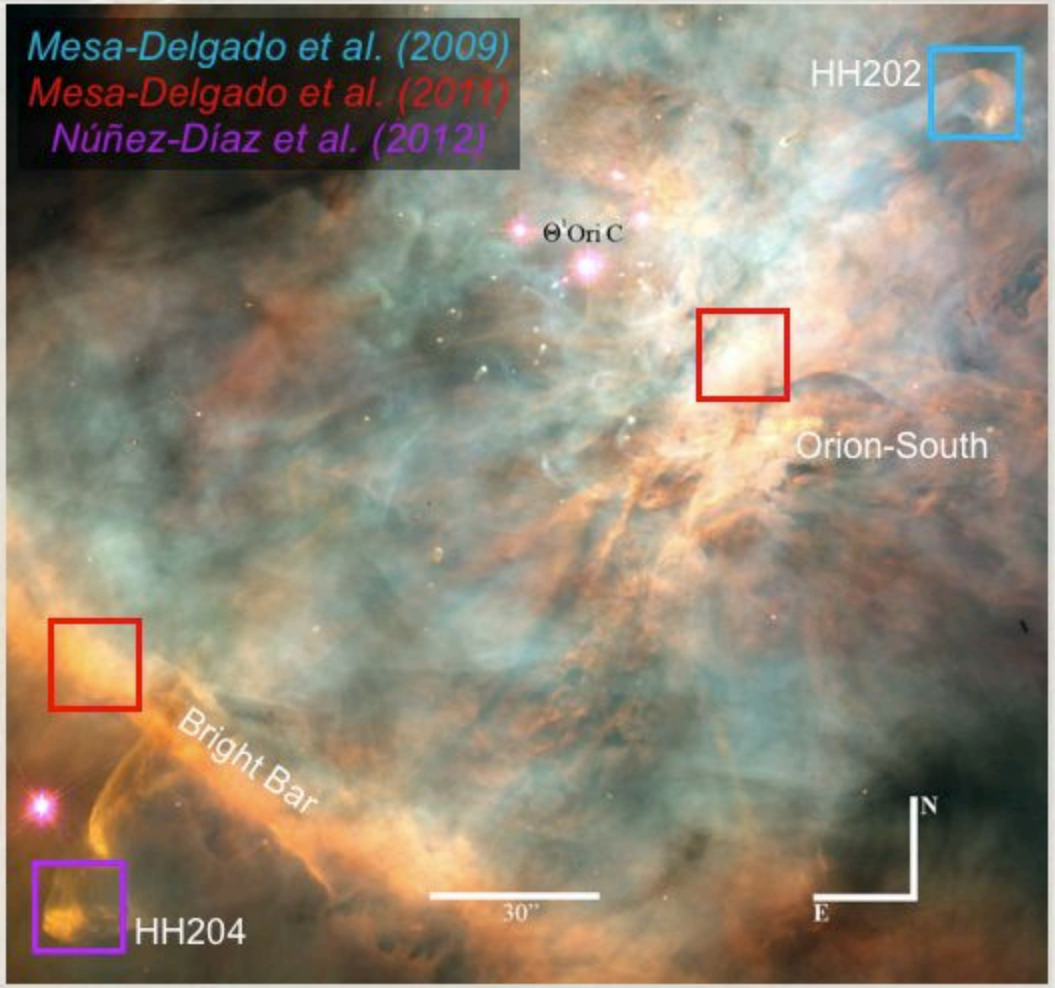
The key question:

Do they have effects on the chemical composition?

**Next step: integral field studies.**

# Observations

- Potsdam Multi-Aperture Spectrograph (PMAS, *Roth et al. 2005*) at 3.5m Telescope (Calar Alto)
- FoV: 16”x16” / 1” sampling
- V600 grating
- Δλ: 3500-5100 and 5700-7200 Å
- Effective resolution: 3.6 Å

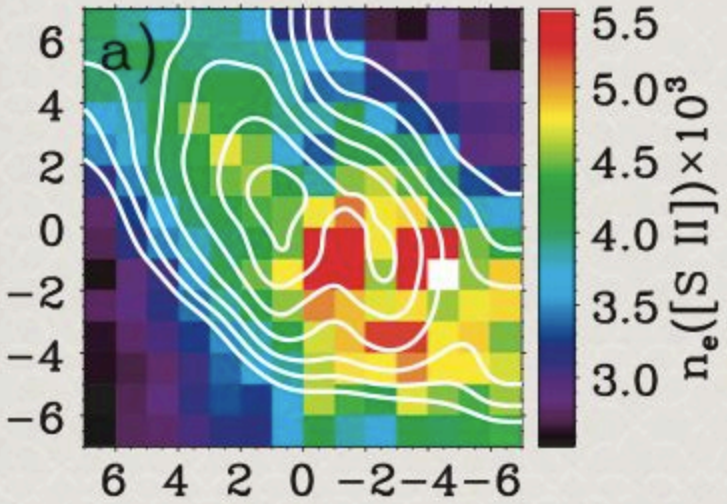


# Spatial Maps

- Emission line fluxes.
- Extinction coefficient: Hγ/Hβ and Hδ/Hβ.
- Electron density: [SII] λ6731/λ6717 line ratio
- Electron temperatures: [OIII] λ5007/λ4363 and [NII] λ6584/λ5755 line ratios.
- Abundances: $O^{+}/H^{+}$, $O^{2+}/H^{+}$, O/H.

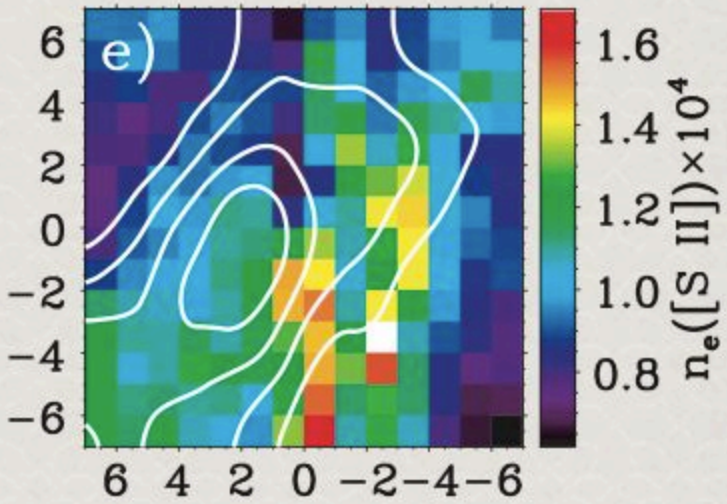
# Mapping Bars

## Bright Bar




Density peaks ~ 6,000 cm$^{-3}$

## Orion-S

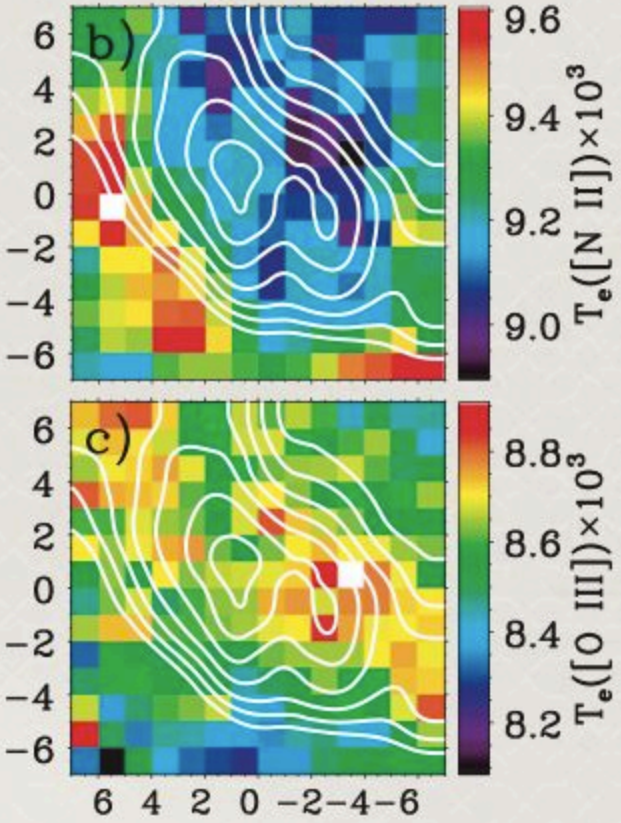



Density peaks ~ 16,000 cm$^{-3}$

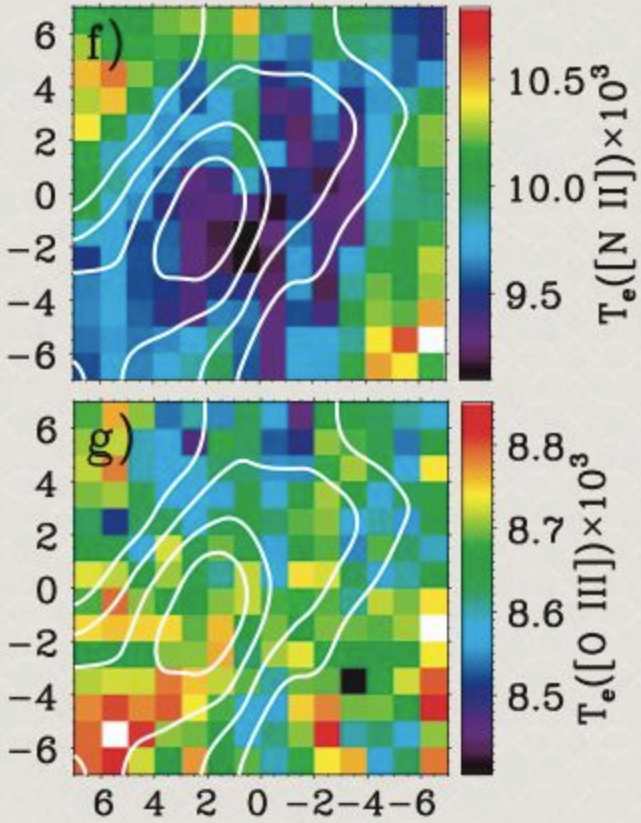
- Highest values are of about high-density limit of [SII] line ratio.
- Nominal values of density could not be correct.
- $n_e$([FeIII]) points to similar densities, but larger uncertainties.

# Mapping Bars

## Bright Bar



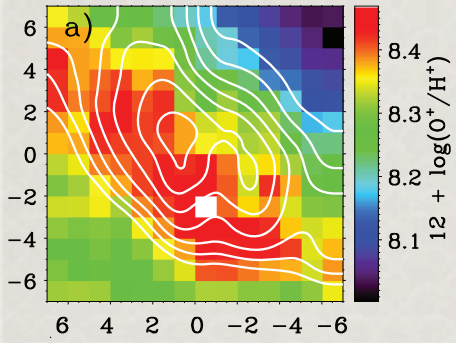

## Orion-S



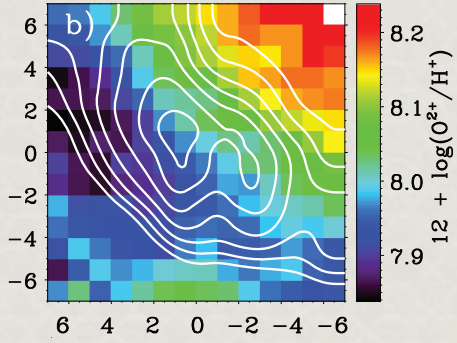
# Mapping Bars

## Bright Bar

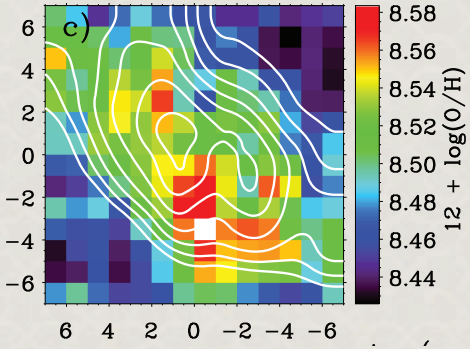
±0.12 dex




±0.03 dex

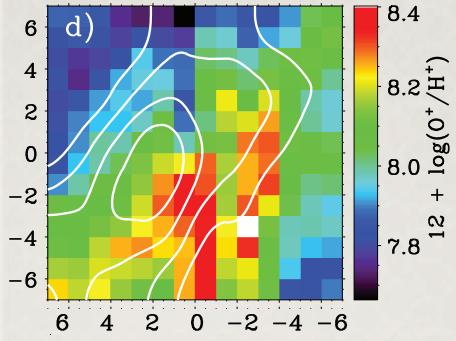



±0.07 dex

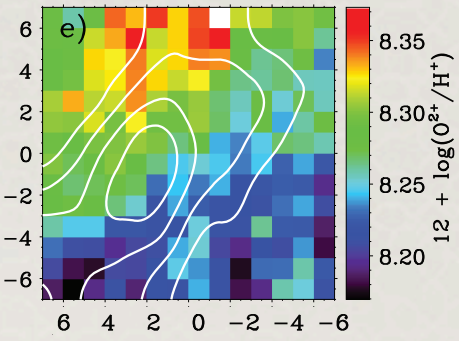



## Orion-S

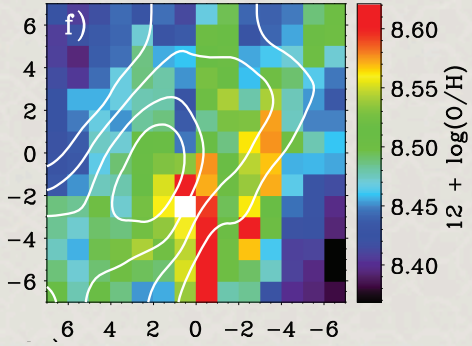
±0.15 dex




±0.03 dex




±0.07 dex

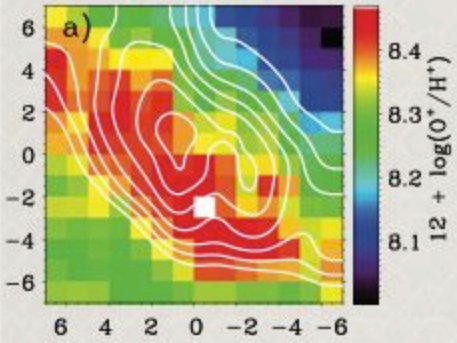



- O/H have structure.
- Average O/H:
  - Bright Bar 8.49±0.03
  - Orion-S 8.48±0.05
- Variations above quoted errors.
- Structure O/H ≈ $O^+/H^+ \approx n_e$.

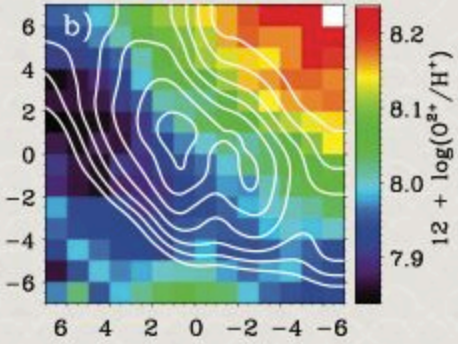
# Mapping Bars

## Bright Bar

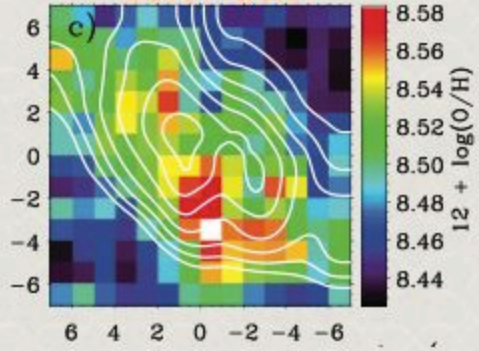
±0.12 dex

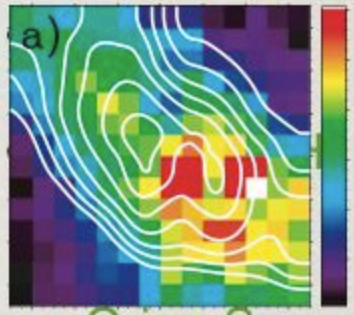



±0.03 dex




±0.07 dex

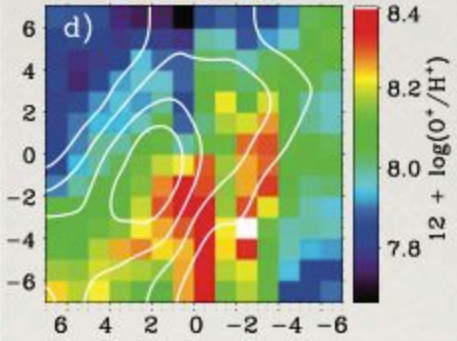


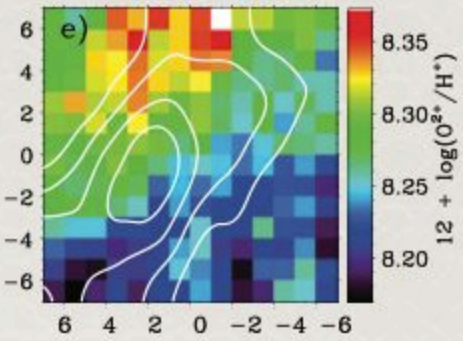

- Orion-S 8.48±0.05
- Variations above quoted

## Orion-S

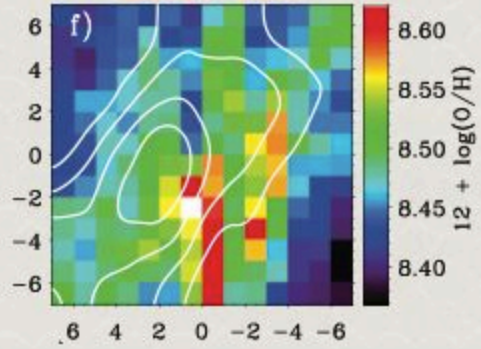
±0.15 dex




±0.03 dex

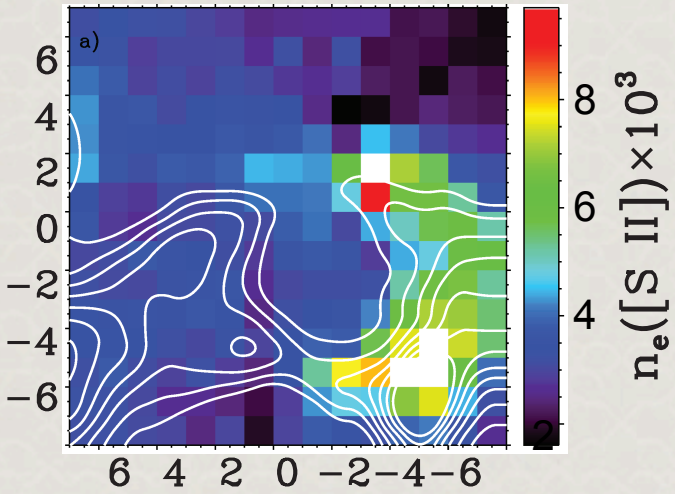



±0.07 dex

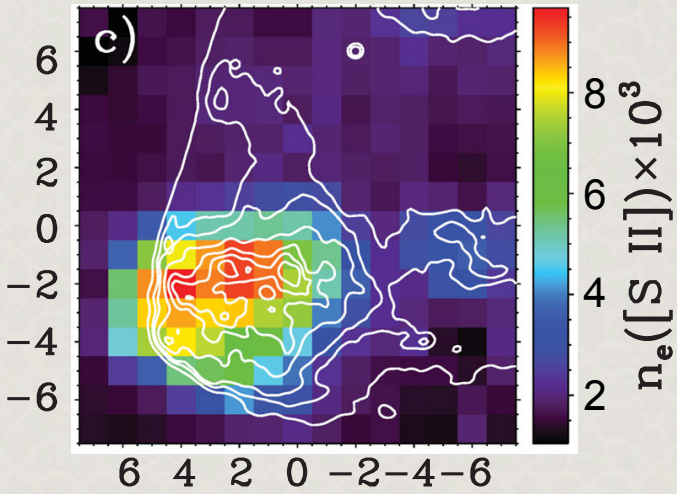



# Mapping HH Objects

## HH202



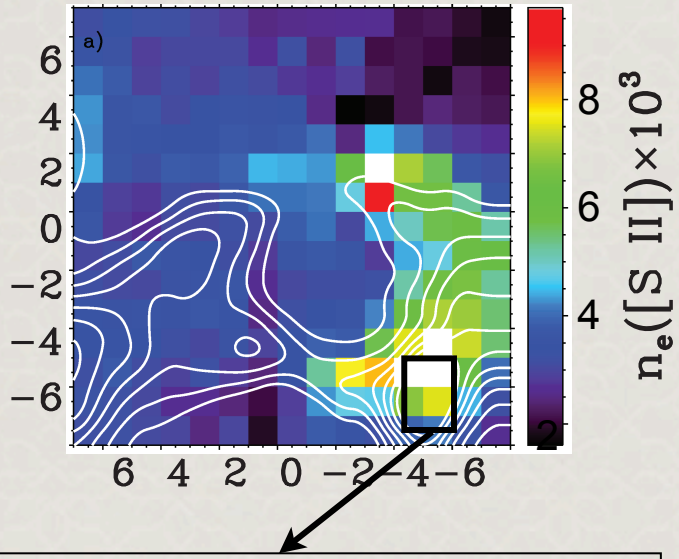

## HH204




- Density peaks ~ 9,000 $cm^{-3}$.
- Similar effects observed in the Bars.
- Are densities real?

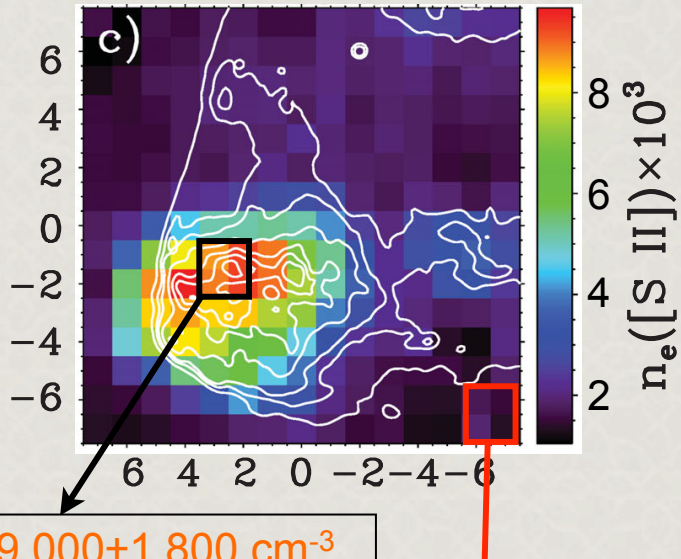
# Mapping HH Objects

## HH202




High-resolution UVES spectroscopy (*Mesa-Delgado et al. 2009*):
$n_e$(background) = 2,890±550 cm$^{-3}$
$n_e$(gas flow) = 17,430±2,360 cm$^{-3}$

## HH204

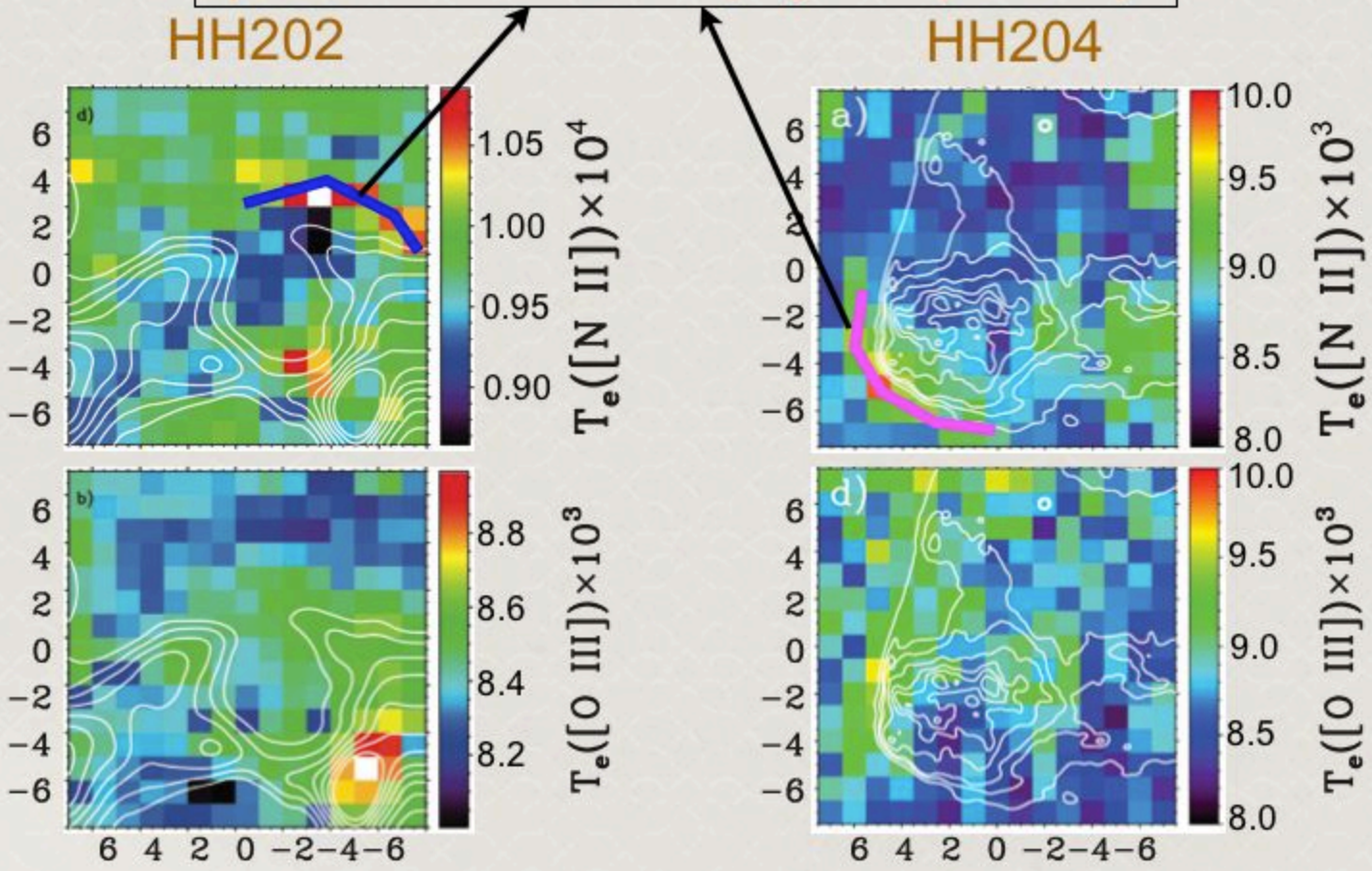



$n_e$([SII]) = 9,000±1,800 cm$^{-3}$
$n_e$([FeIII]) = 15,300±5,600 cm$^{-3}$

$n_e$([SII]) = 1,400±300 cm$^{-3}$
$n_e$([FeIII]) = 2,800±1,900 cm$^{-3}$

# Mapping HH Objects

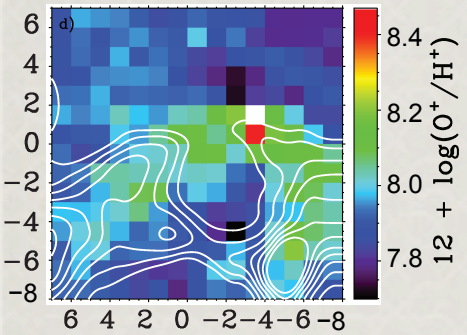
First time reported: high-$T_e$ arcs predicted in photoionized HH models (*Raga & Reipurt 2004*).



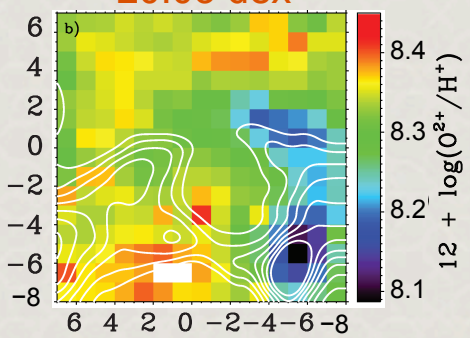
# Mapping HH Objects

## HH202

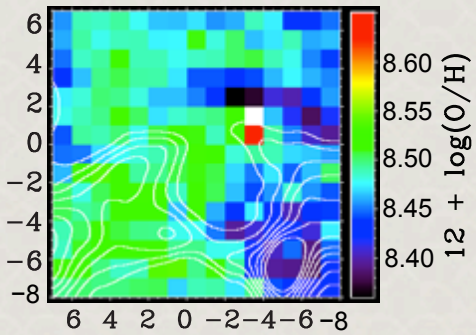
±0.11 dex




±0.03 dex

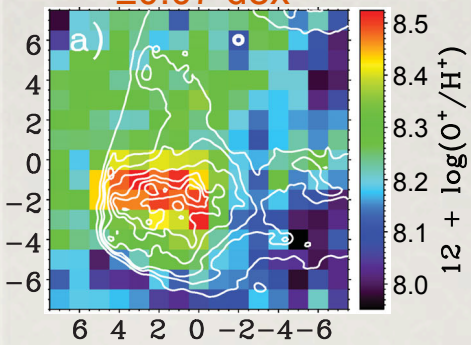



*±0.05 dex*

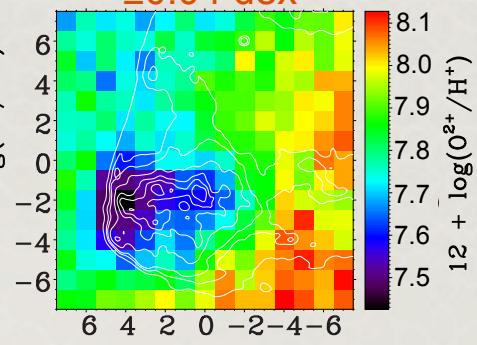



## HH204

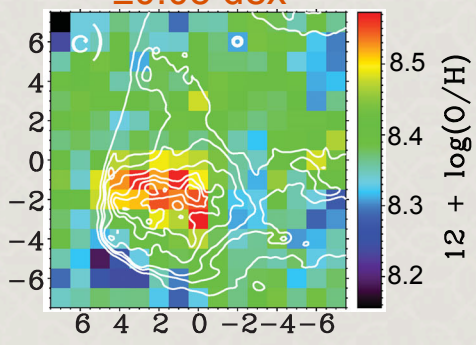
±0.07 dex




±0.04 dex




±0.05 dex



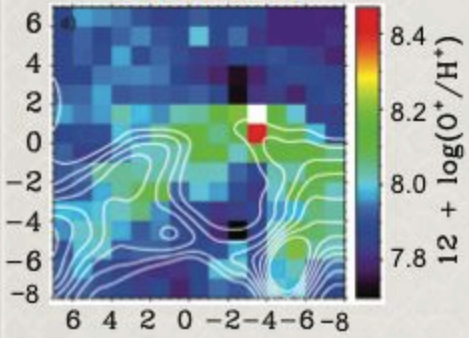

- O/H have structure.
- Average O/H:
  - HH202 8.48±0.04
  - HH204 8.40±0.10
- Minimum O/H at the high-$T_e$ arcs
- Structure O/H ≈ $O^+/H^+$≈ $n_e$.

# Mapping HH Objects

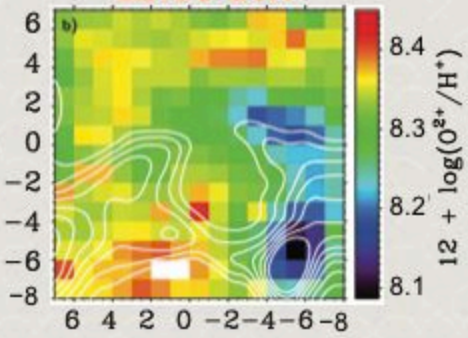
Well, not exactly! Now, we also have effects of high-Te arcs.

## HH202

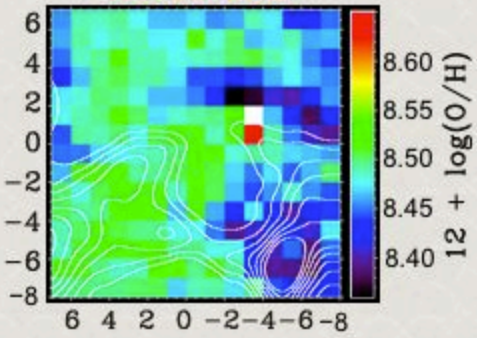
±0.11 dex

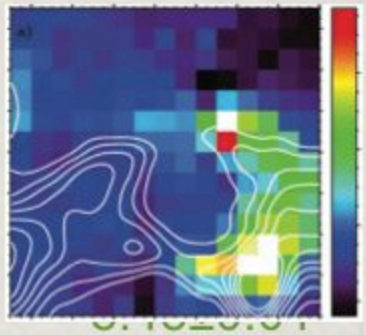



±0.03 dex



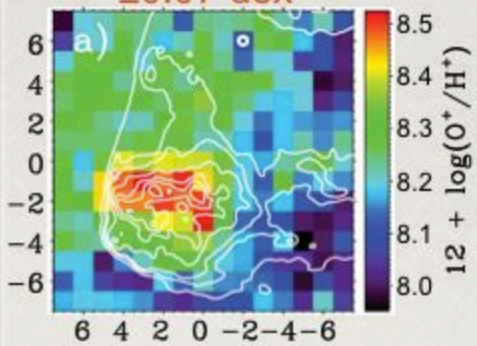

±0.05 dex



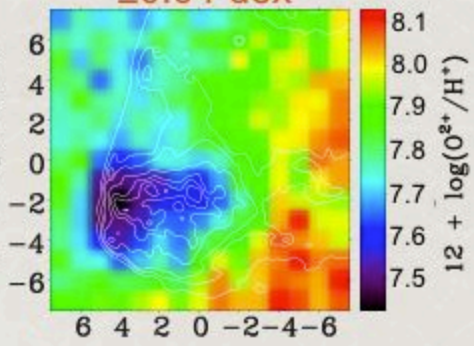



## HH204

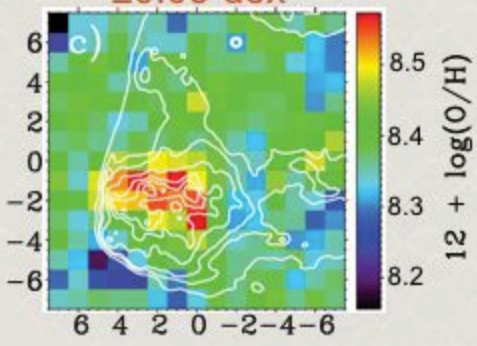
±0.07 dex

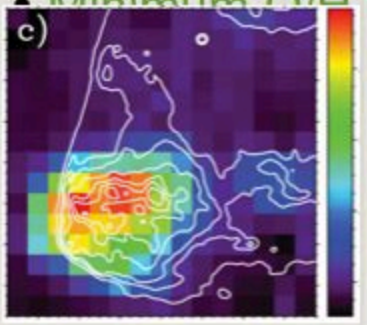



±0.04 dex




±0.05 dex




- HH204 8.40±0.10

# Summary

- The obvious conclusion: HII regions are complex.
- Incorrect density values are severely affecting determinations based on low critical density lines. Extreme case: proplyds (*Tsamis' and Flores-Fajardo's talks*).
- Discover of shock-heated areas at the leading working surface of photoionized HH objects.

# Summary

- High-$T_e$ arcs modify the elemental oxygen abundance of Orion.
- Can we quantify the global effect? Next step: the big mosaic of Orion (*Morisset's and Núñez-Díaz' s talks*).
- My concern: what is happening in more distant HII regions?

Thanks!!!