



MAX-PLANCK-GESELLSCHAFT



Re-evaluation of the cosmic-ray ionization rate in diffuse clouds

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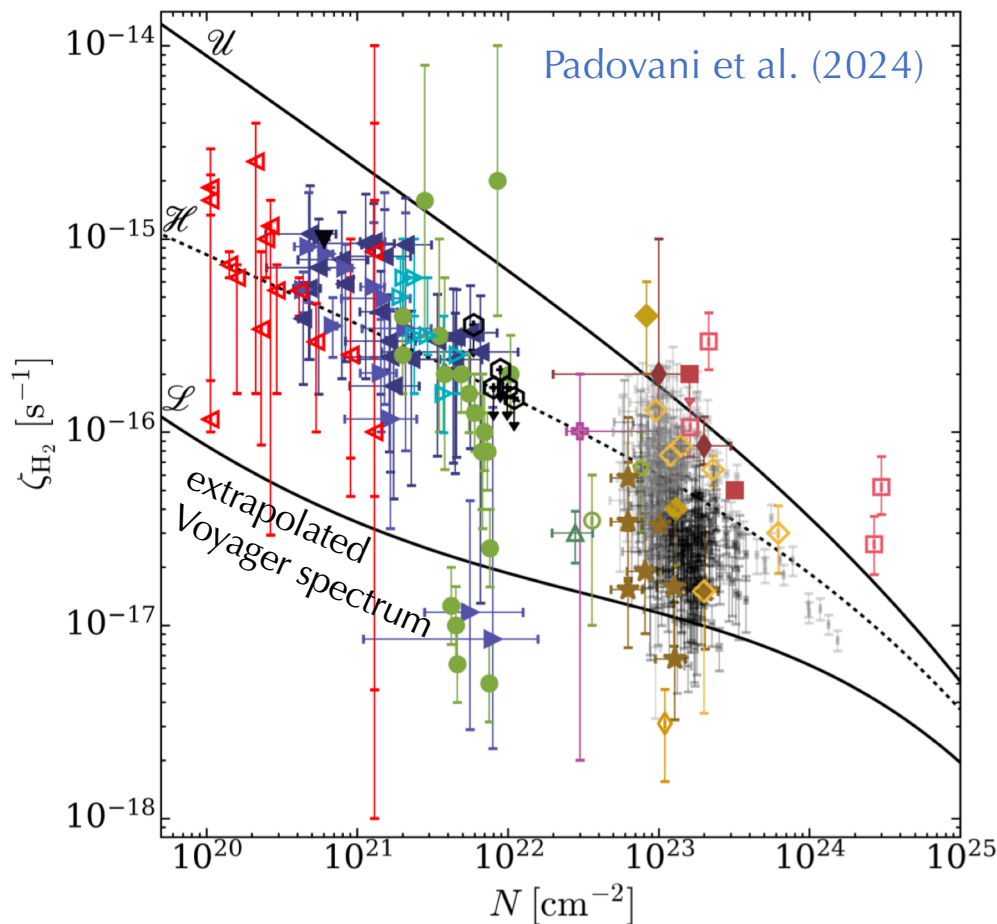
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Variety of processes driven by low-energy CRs

- Gas ionization
 - ⇒ coupling to magnetic field, properties of turbulence, ...
- Gas heating
 - ⇒ cloud dynamics, chemistry, ...
- Dust evolution
 - ⇒ dust coagulation, chemical processes on grain surface, ...
- Processing of icy mantles
 - ⇒ abundances of complex molecules, desorption of ices, ...
- ...

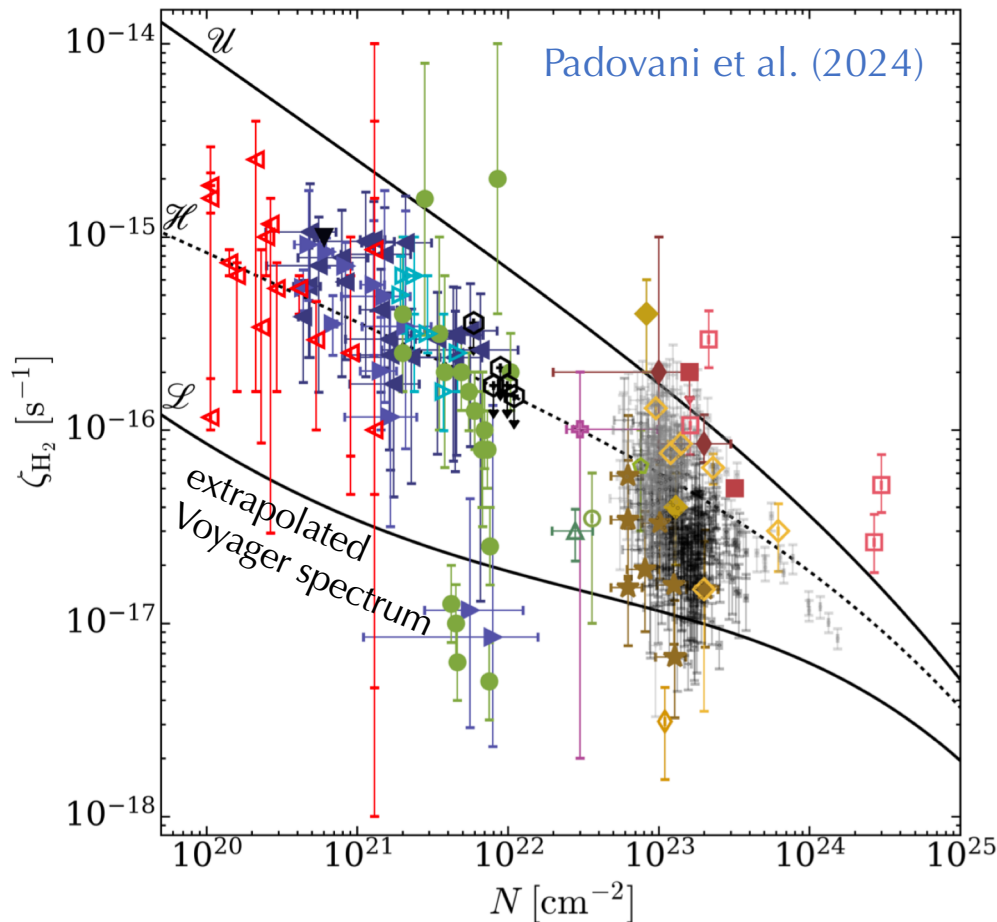
Measurements of CR ionization rate ζ



Specific ions generated by CRs are measured in absorption or emission:

- Atomic gas, ζ_{H} : OH^+ , H_2O^+ , ArH^+ , ...
- Molecular gas, ζ_{H_2} : H_3^+ , HCO^+ , H_2D^+ , ...

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Irrespective of the tracer, the deduced parameter is always ζ/n_{tot} .

Total density $n_{\text{tot}} = n_{\text{H}} + 2n_{\text{H}_2}$ is evaluated from measuring rotational states of C_2 (Sonnentrucker et al. 2007).

Re-evaluated H_3^+ measurements: targets

Observations of H_3^+ ions **in absorption** are considered as the most reliable method to measure the H_2 ionization rate in diffuse molecular clouds ([Indriolo & McCall 2012](#)).

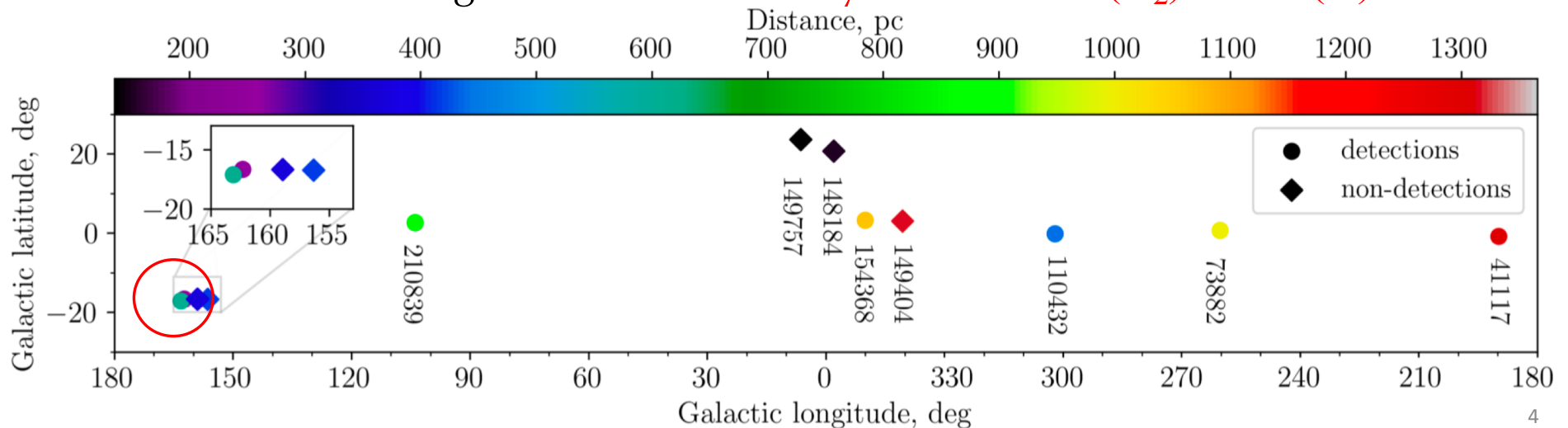
$$\zeta_{\text{H}_2} n_{\text{H}_2} = k n_{\text{H}_3^+} n_e \quad \Rightarrow \quad \boxed{\zeta_{\text{H}_2} = k x_e n_{\text{tot}} \frac{N(\text{H}_3^+)}{N(\text{H}_2)}}$$

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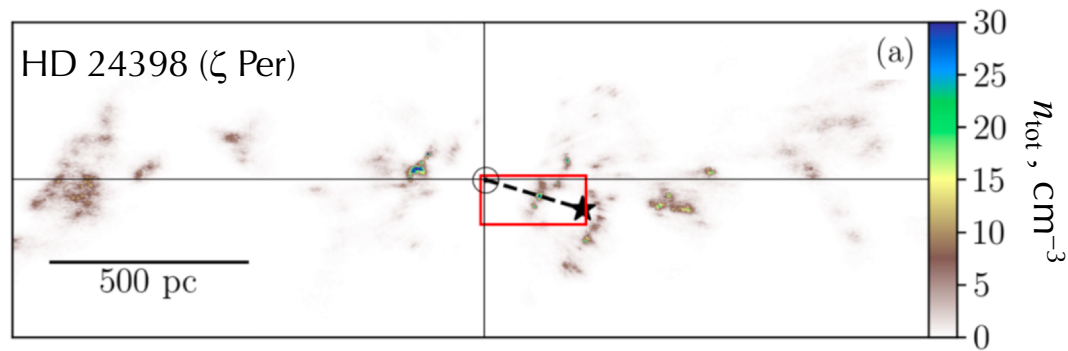
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We selected target stars with **directly measured $N(\text{H}_2)$ and $N(\text{H})$** :

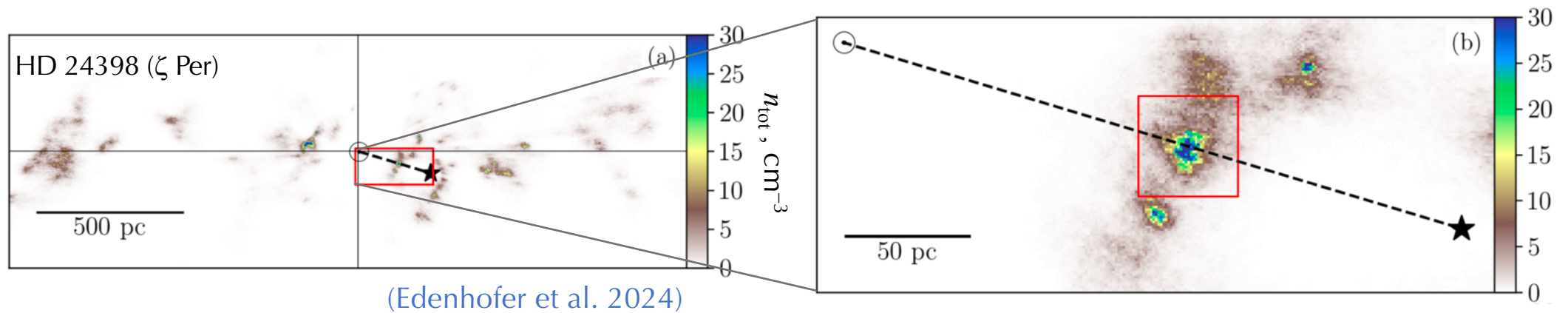


Gas distribution from 3D dust extinction maps

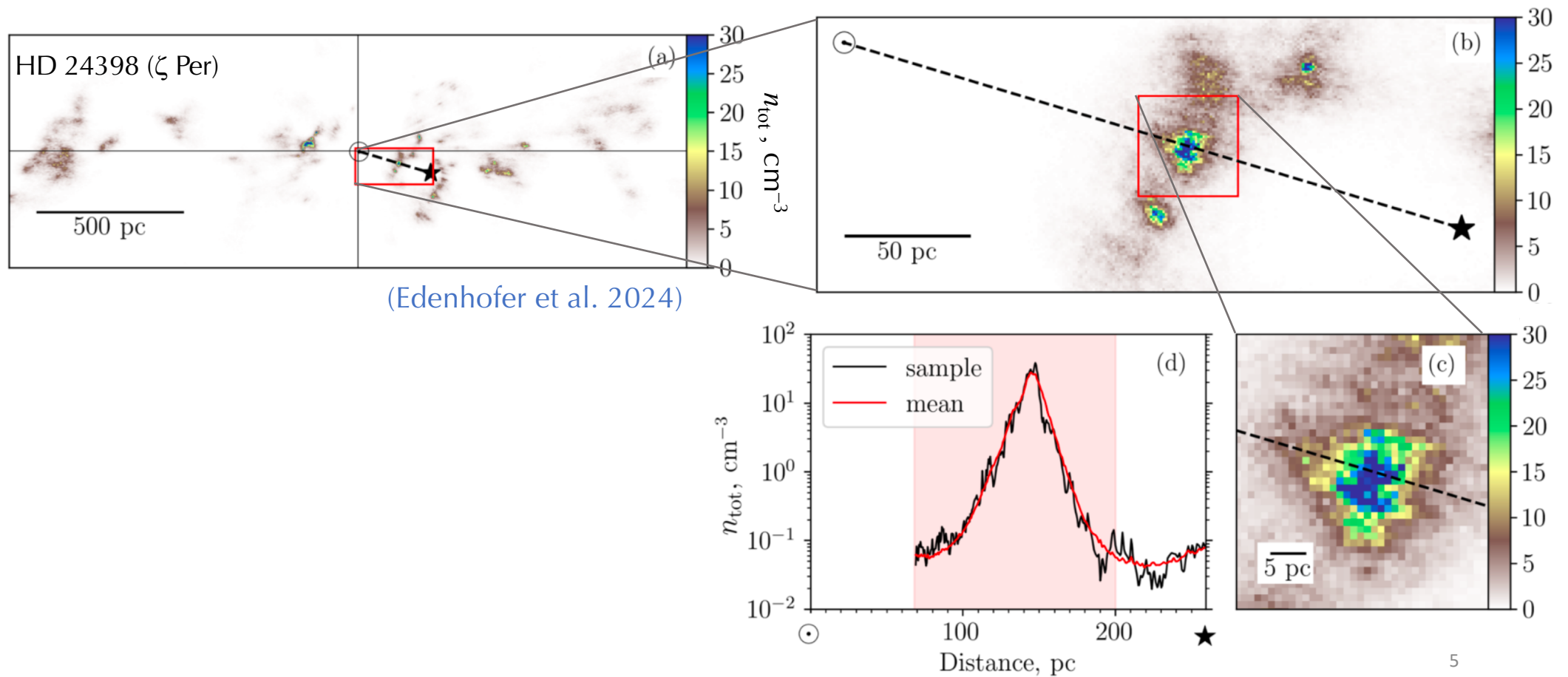


(Edenhofer et al. 2024)

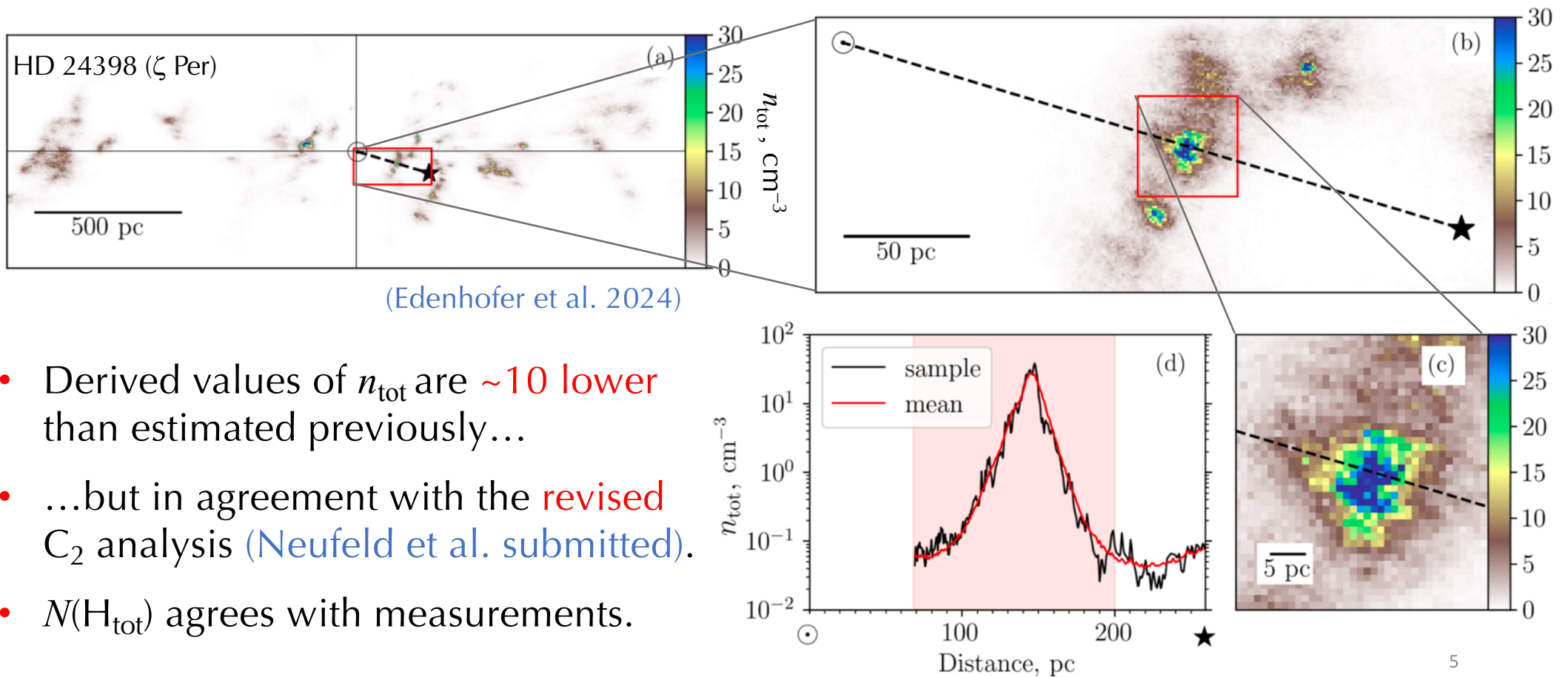
Gas distribution from 3D dust extinction maps



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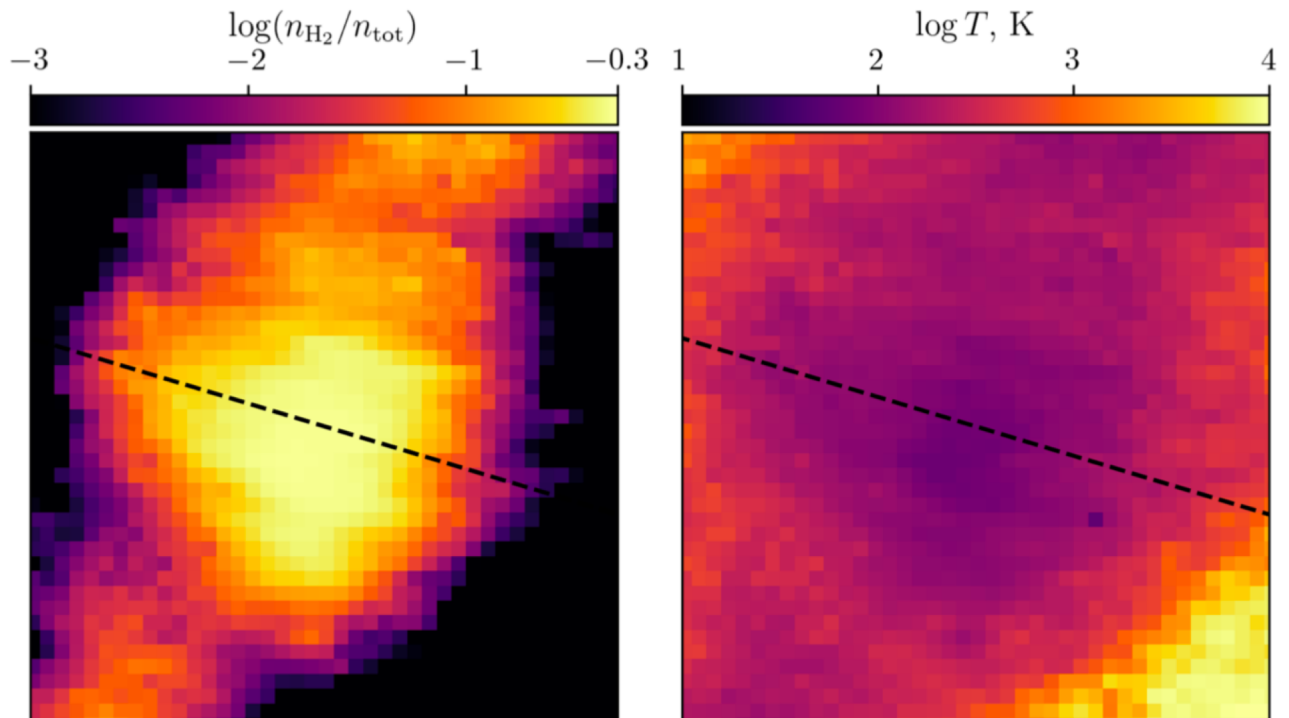
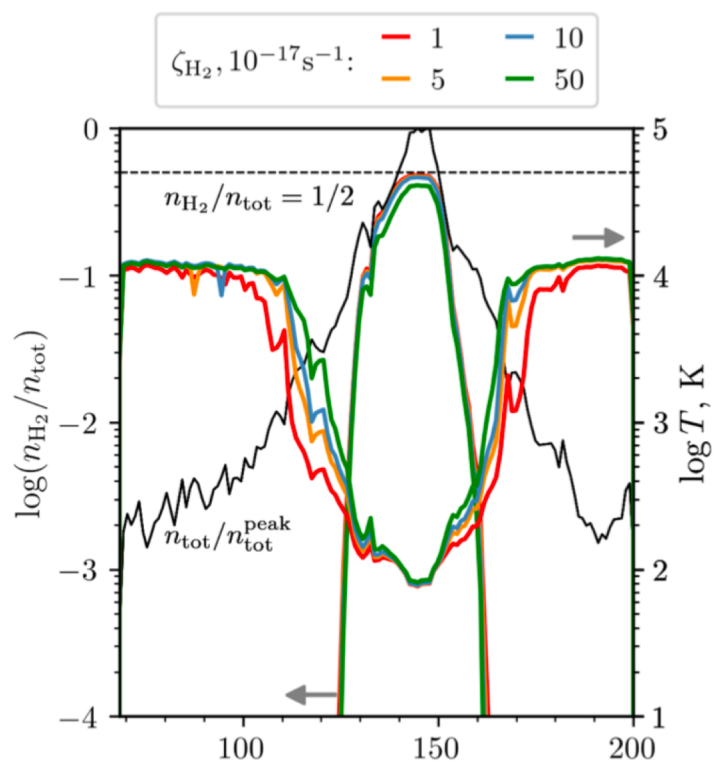


Gas distribution from 3D dust extinction maps



Simulated 3D physical structure of gas clumps

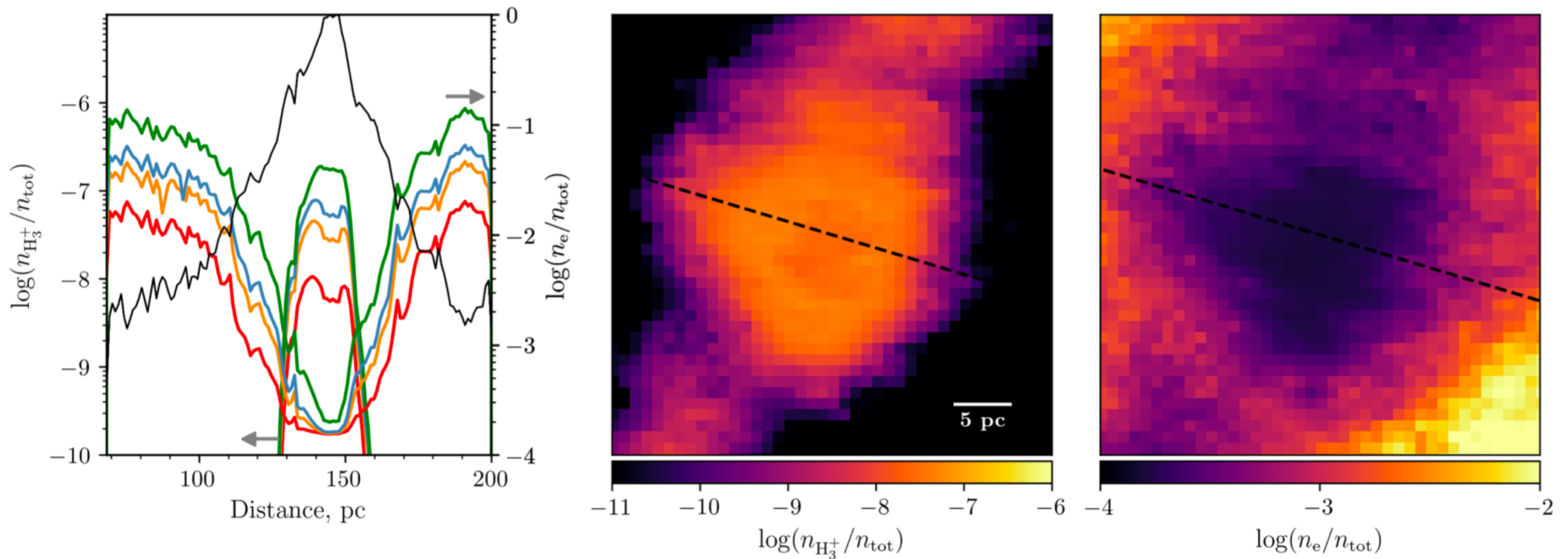
3D PDR code (Bisbas et al. 2012)



ζ_{H_2} is the only unconstrained parameter

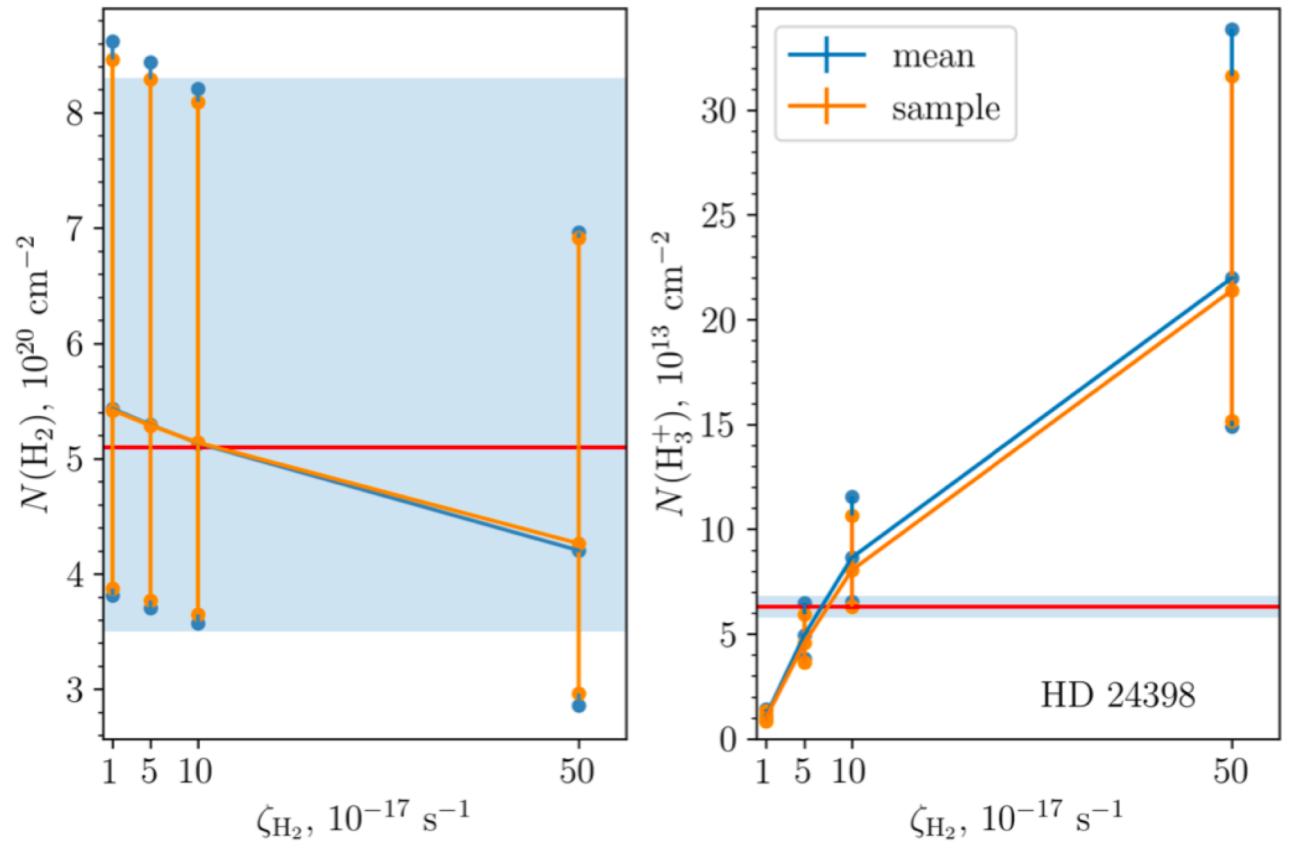
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Simulations versus observations

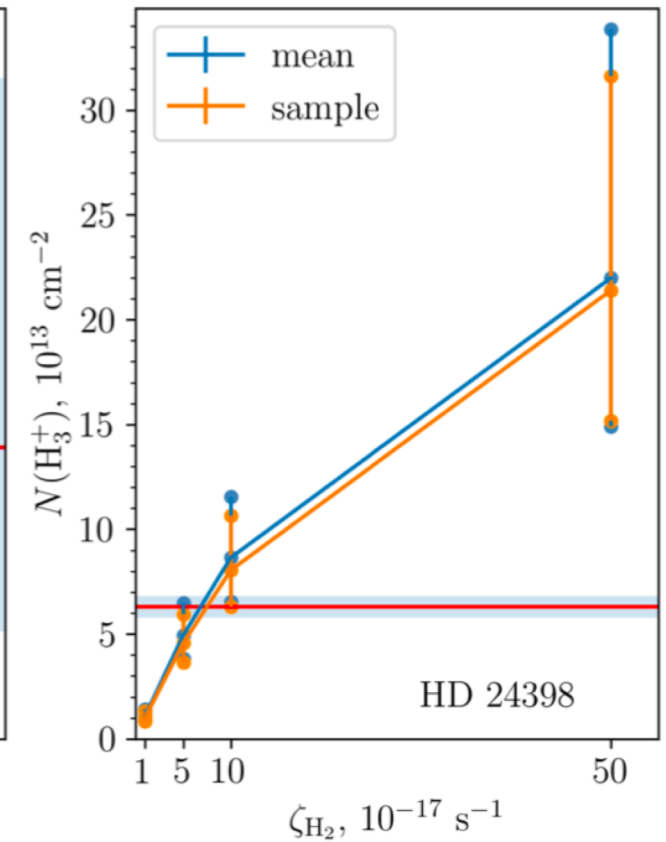
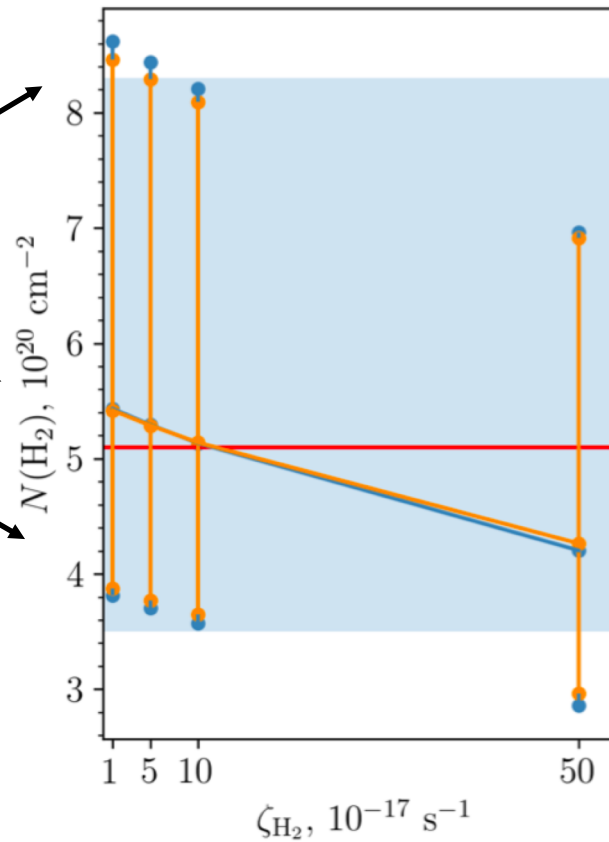


Simulations versus observations

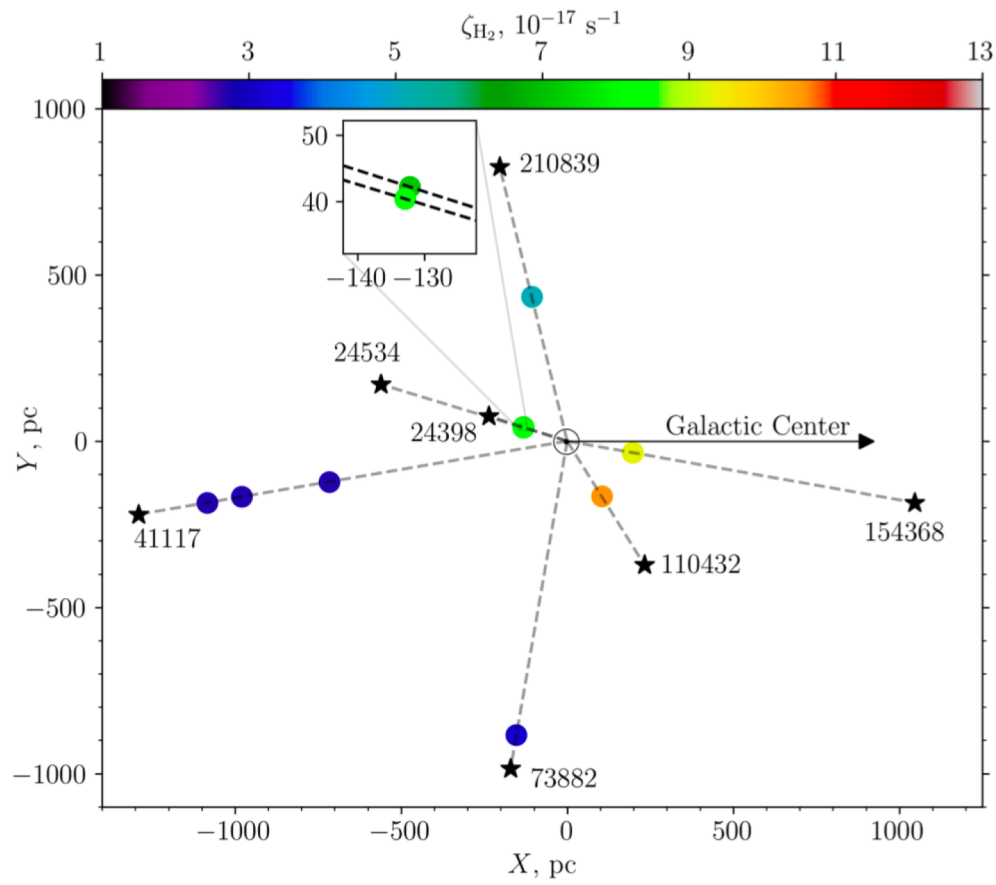
Simulations for the
mean measured $N(\text{H}_{\text{tot}})$
and for 68%
confidence limits



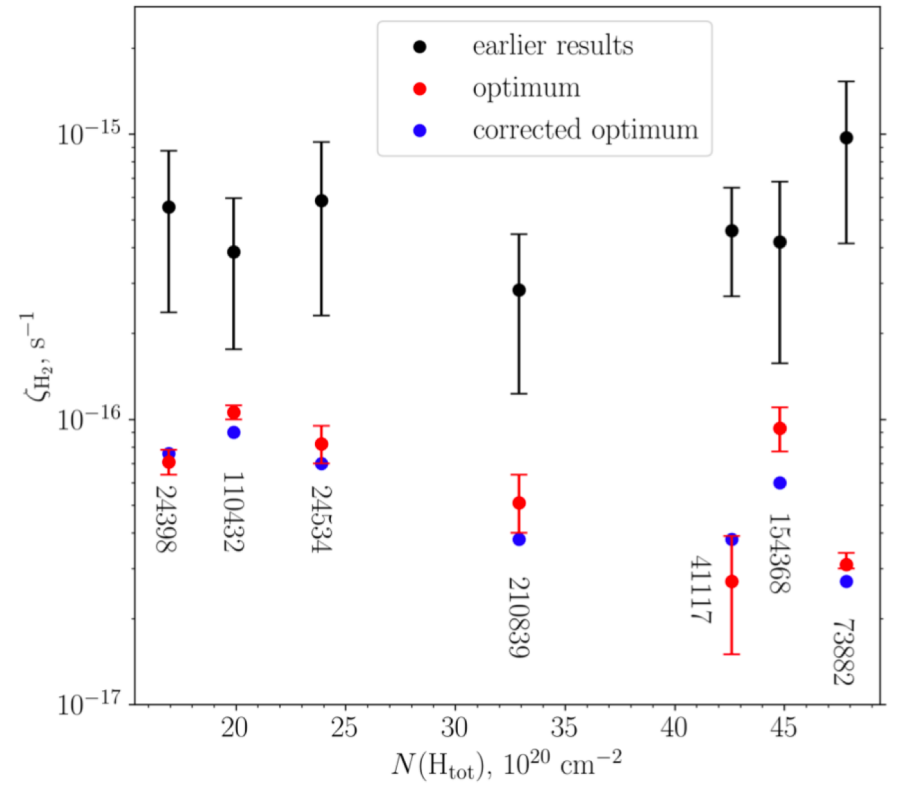
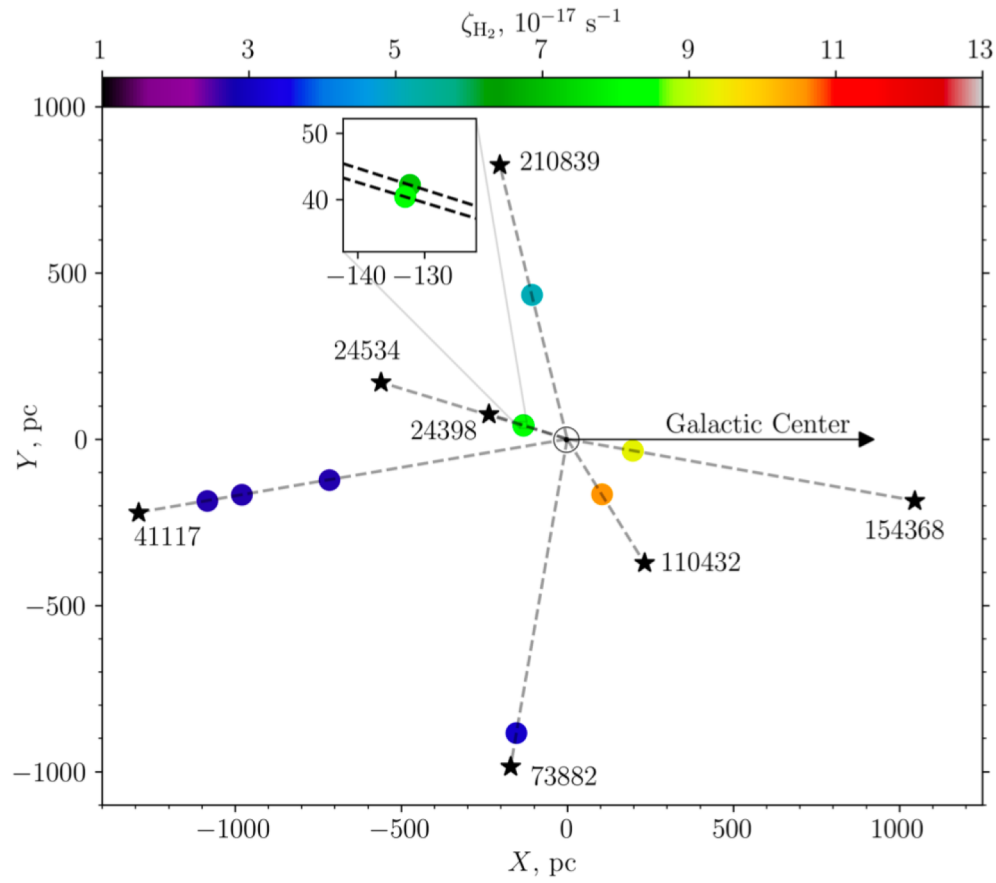
Optimum ζ_{H_2} and $N(\text{H}_{\text{tot}})$



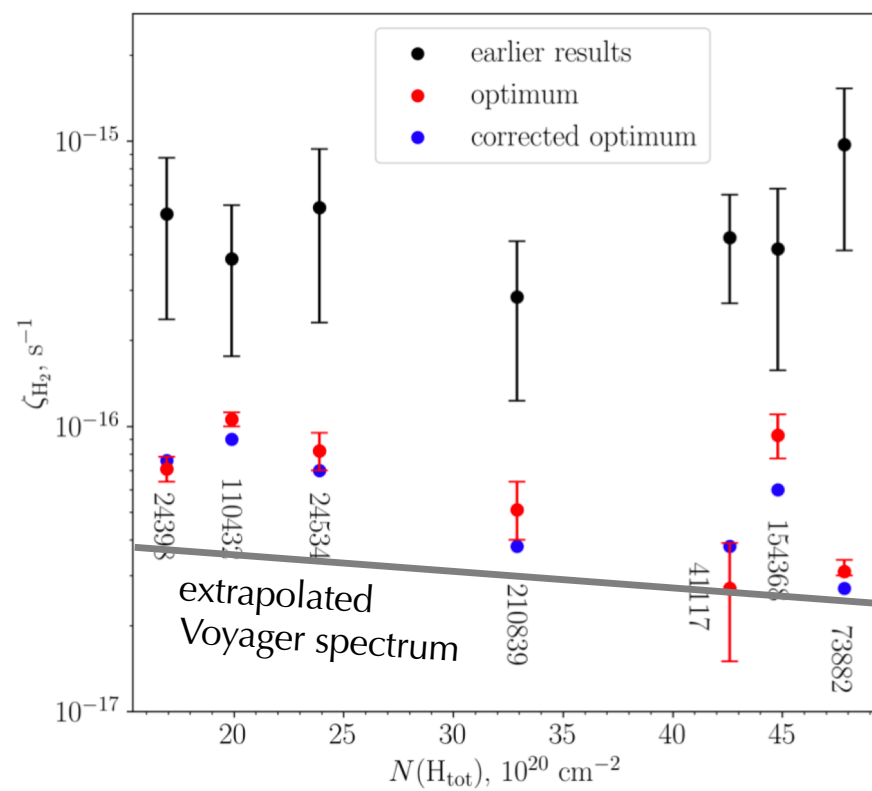
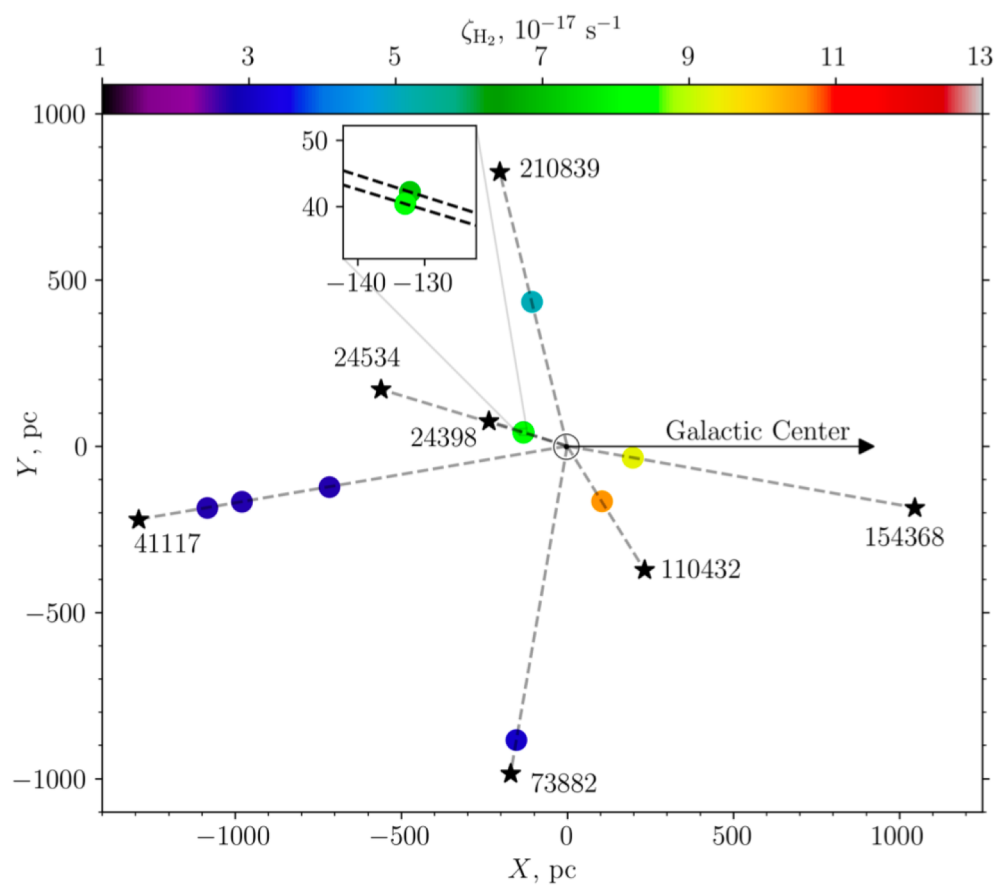
Re-evaluated ionization rate



Re-evaluated ionization rate



Re-evaluated ionization rate



Conclusions and outlook

- High-resolution 3D dust extinction maps enable **accurate localization** of gas clumps where CR ionization is probed.
- Gas densities derived from the maps are (i) **systematically lower** than the previous estimates, and (ii) in agreement with **revised** C_2 estimates (Neufeld et al. submitted).
- Simulations with the 3D PDR code show that ζ_{H_2} is systematically reduced compared to the earlier estimates, **closely following the density reduction**.
- Our results bring the average ζ_{H_2} ($\approx 5.7 \times 10^{-17} \text{ s}^{-1}$) into reasonable agreement with the **Voyager measurements**.
- A careful **re-evaluation for all previously published estimates of ζ_{H_2}** in molecular clouds may be useful.