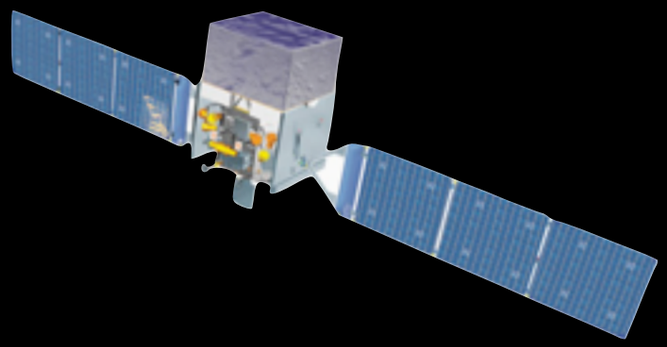
Gas, dust, & cosmic rays in nearby clouds (Cham, Tau, Cal, Per, Cet)

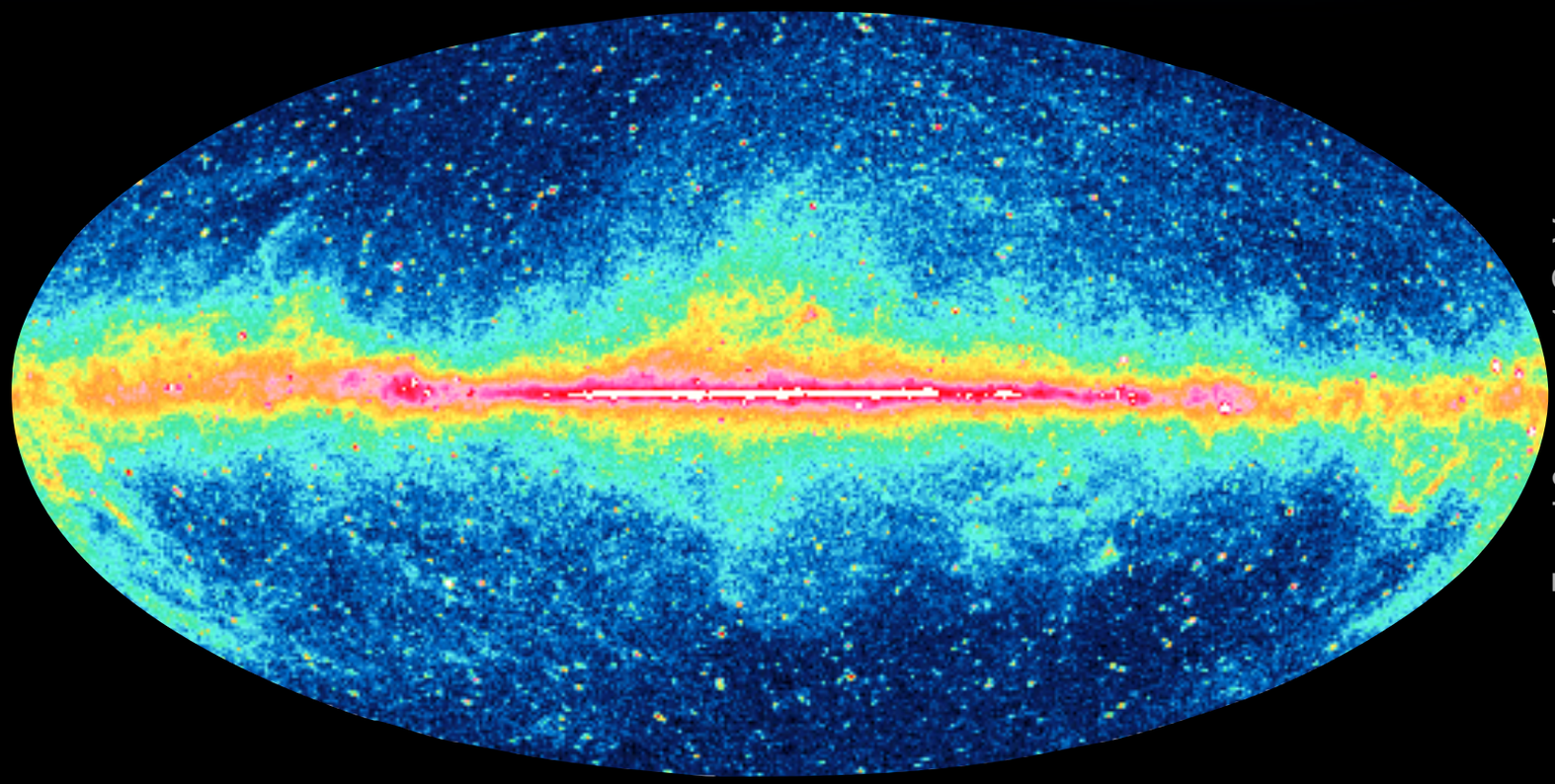
Isabelle Grenier, Quentin Remy,
on behalf of the Fermi LAT Collaboration
AIM, Université Paris Diderot & CEA Saclay

γ rays & dust tracing of the total gas

- Fermi-LAT > 1 GeV

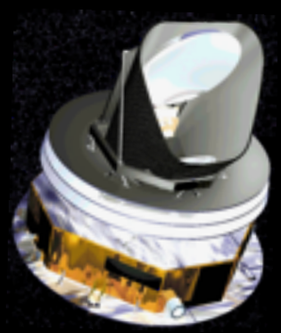


$$\text{diffuse intensity} \propto \int n_{gas}\, n_{CRs}\, dl$$

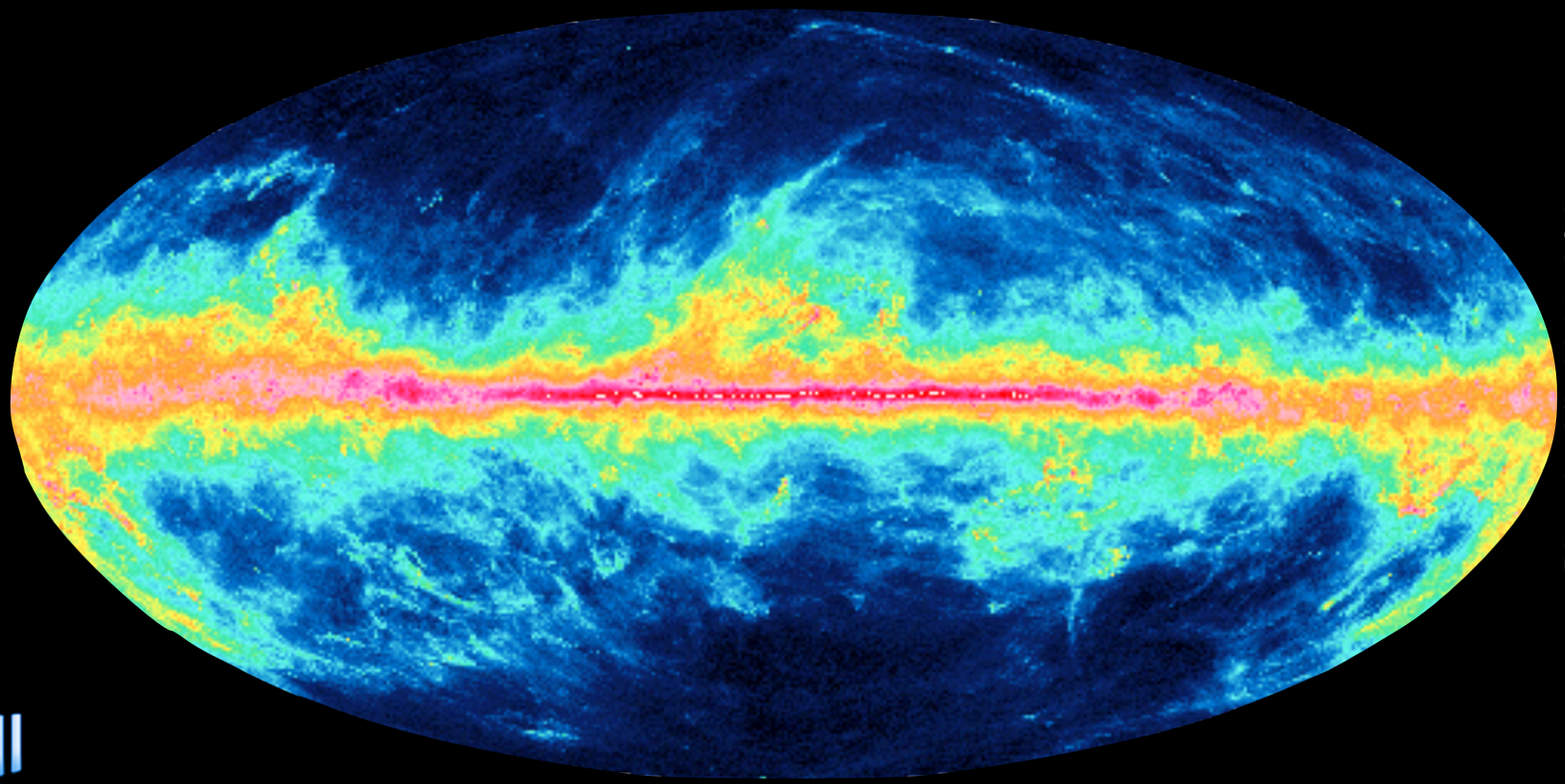


Fermi 6 years > 1 GeV

- Planck + IRAS



$$\text{thermal intensity} \propto \int (M_D/M_{gas})\, \kappa_D\, n_{gas}\, B(T_D)\, dl$$



Planck+.XI, 2014, A&A

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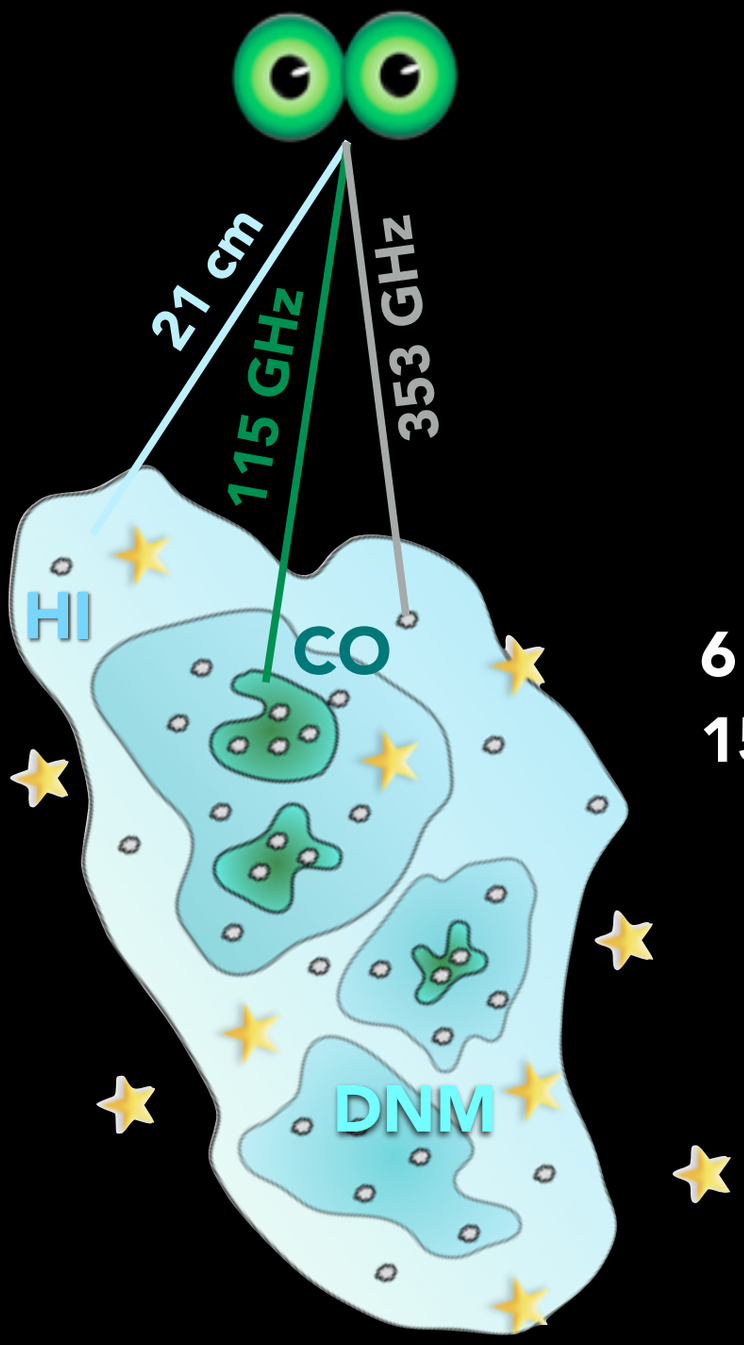
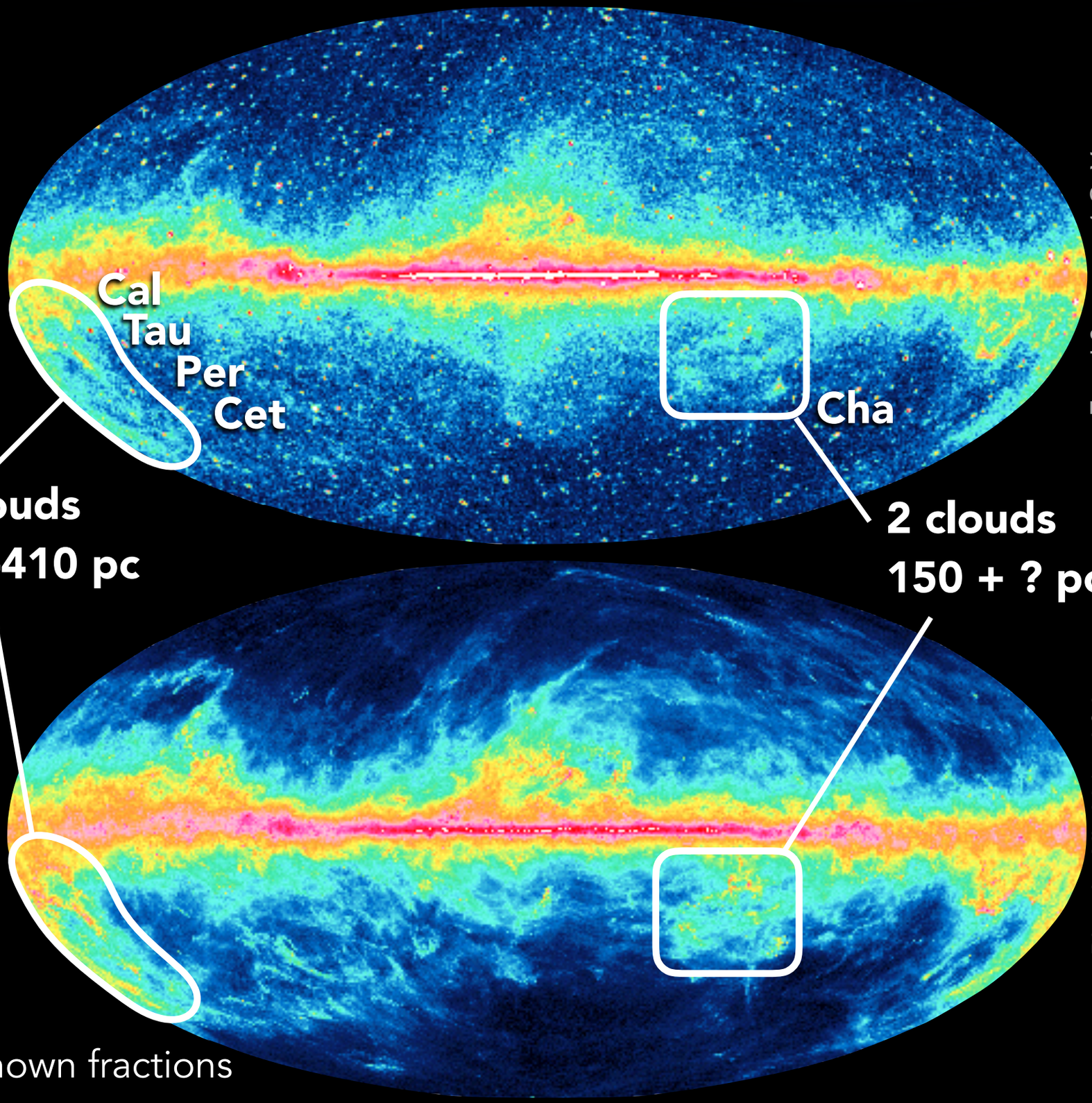
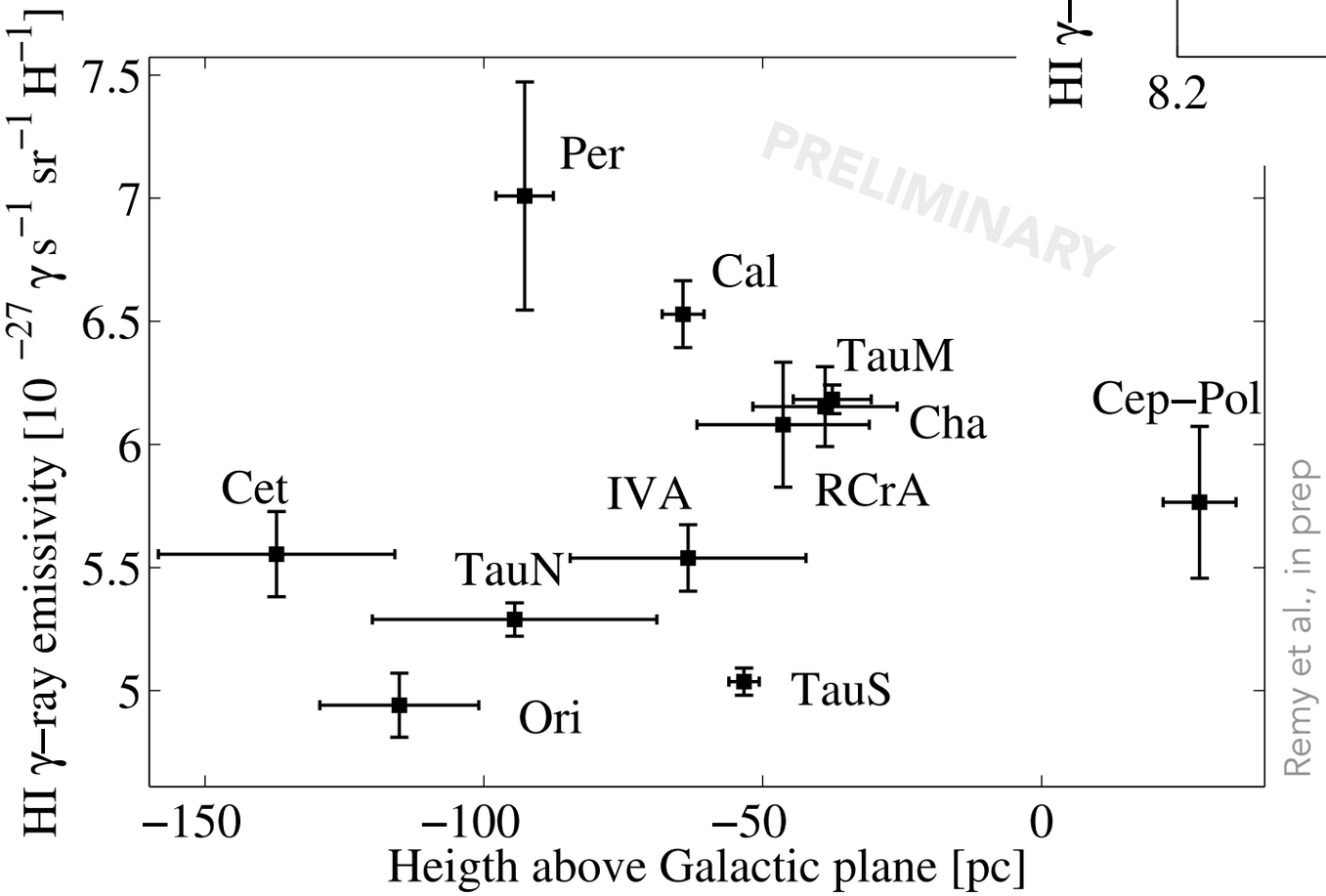


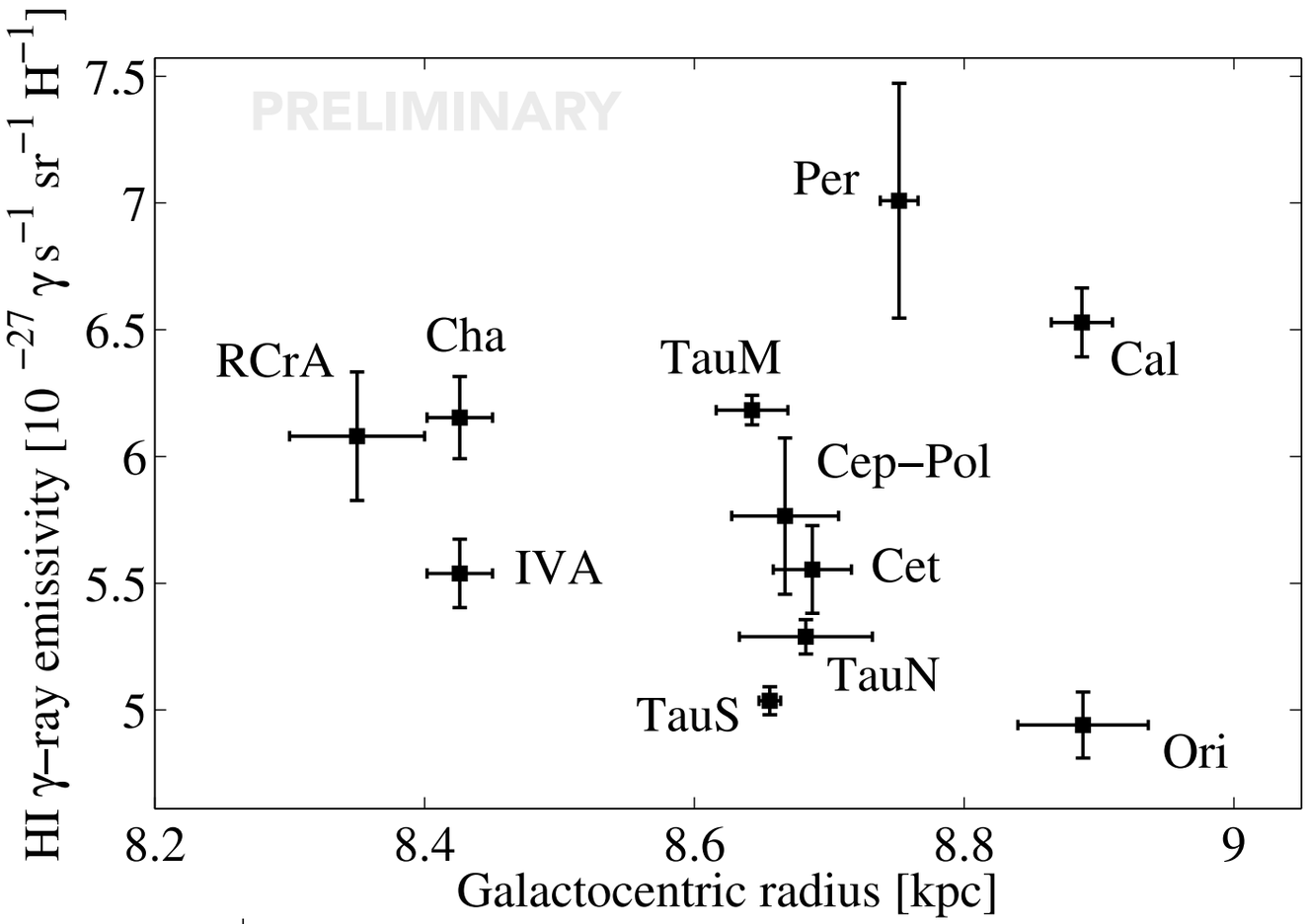


- Dark Neutral Medium:
  opt. thick HI + CO-dark H_2, unknown fractions
- Planck + IRAS

local gas emissivities (0.4-10 GeV)

- 30% variations locally
  - ✦ consistent with uncertainties in the derivation of HI column densities
- no trend with radial distance in the Galaxy (too short a span)
- no trend with altitude above/below the Galactic plane

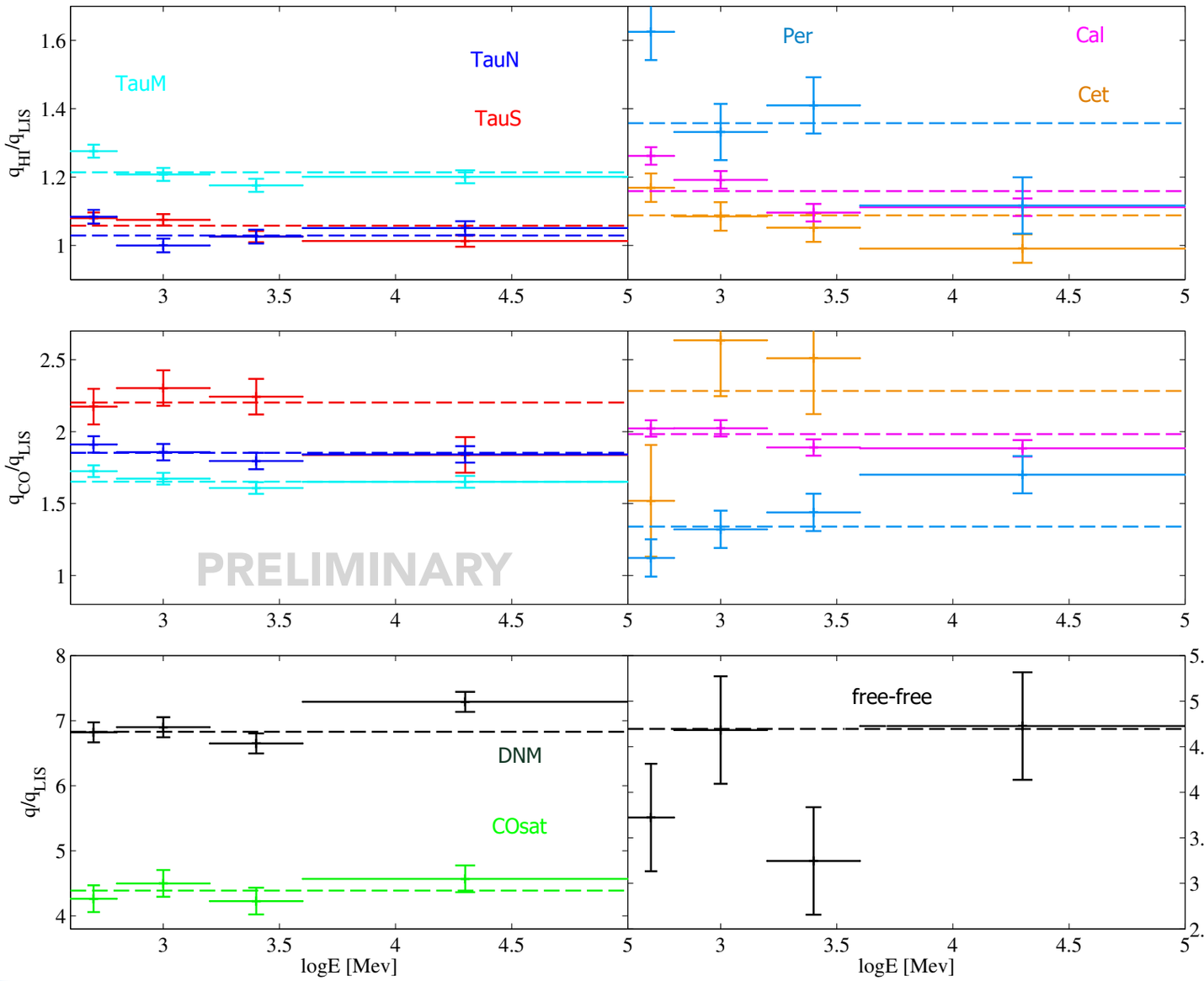




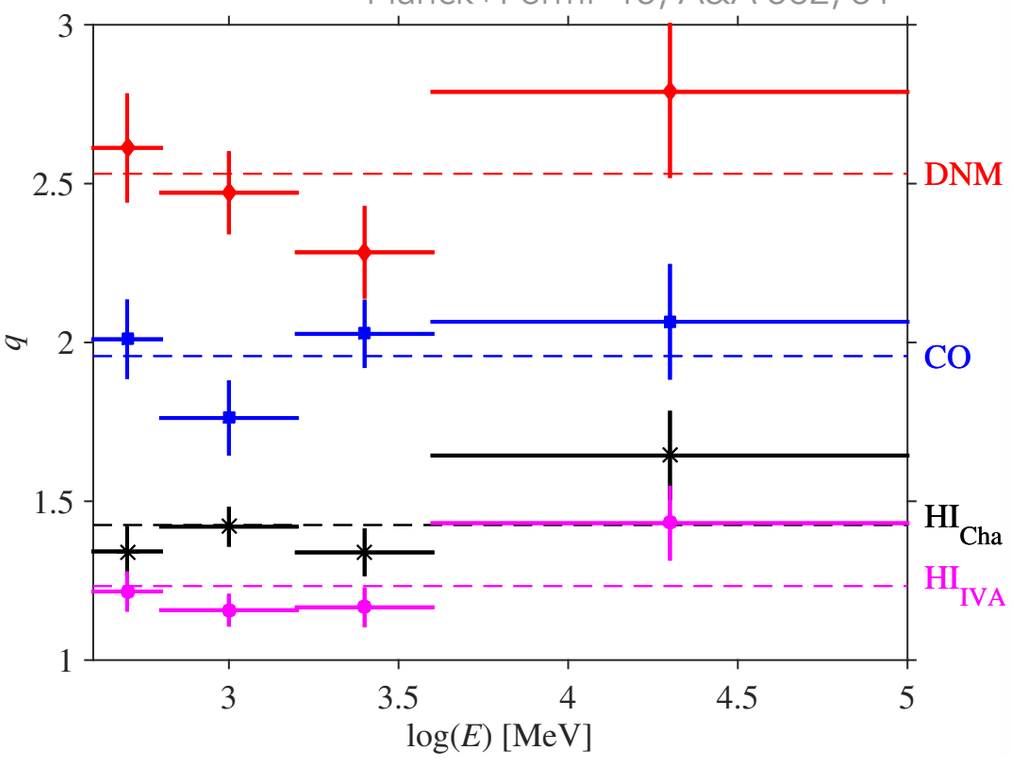
uniform CR penetration inside clouds

- no spectral deviations across the HI, DNM, and H_2 gas phases, down to pc scale
- ≈ uniform CR penetration at the current precision

Remy et al., in prep



Planck+Fermi '15, A&A 582, 31



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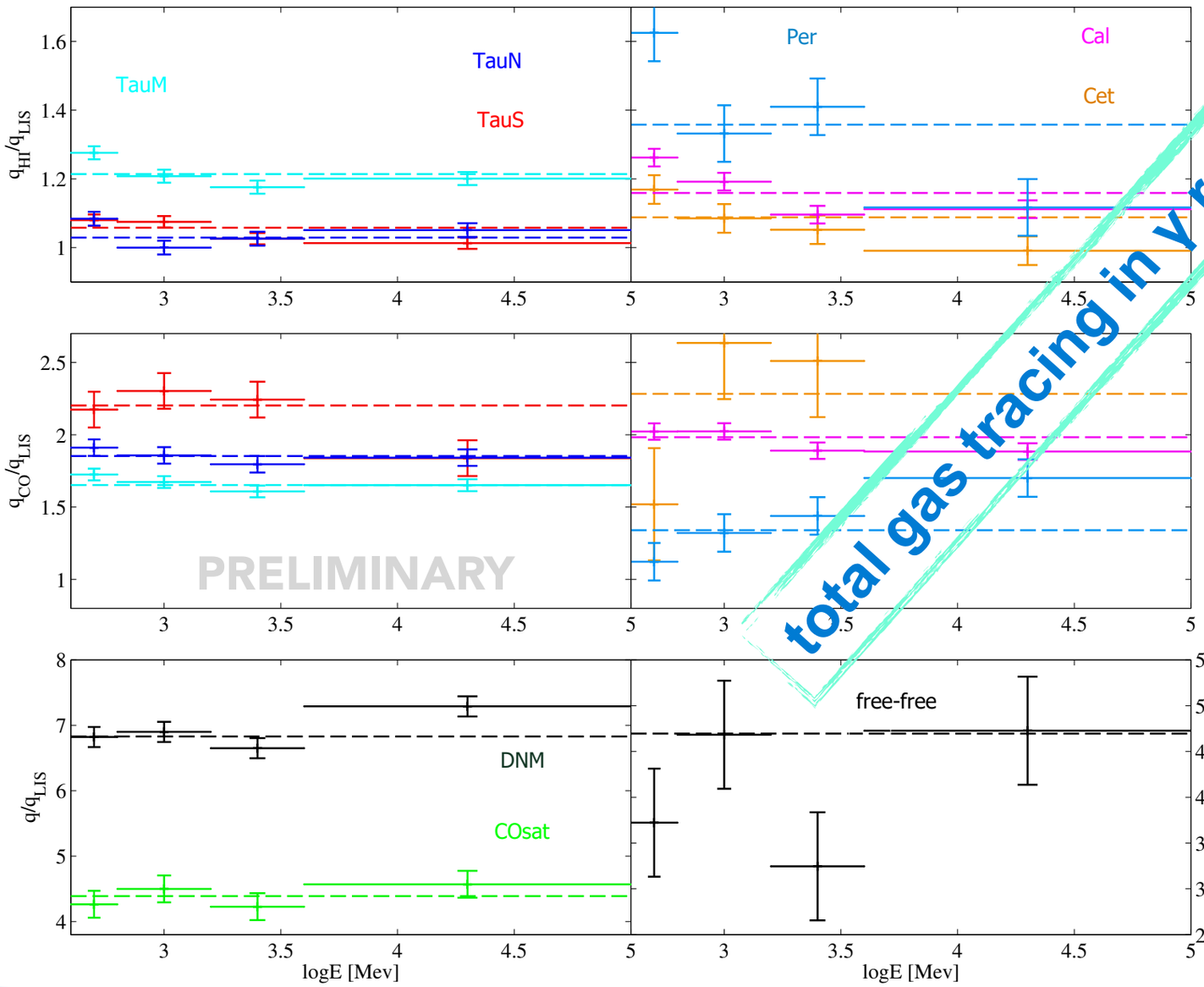
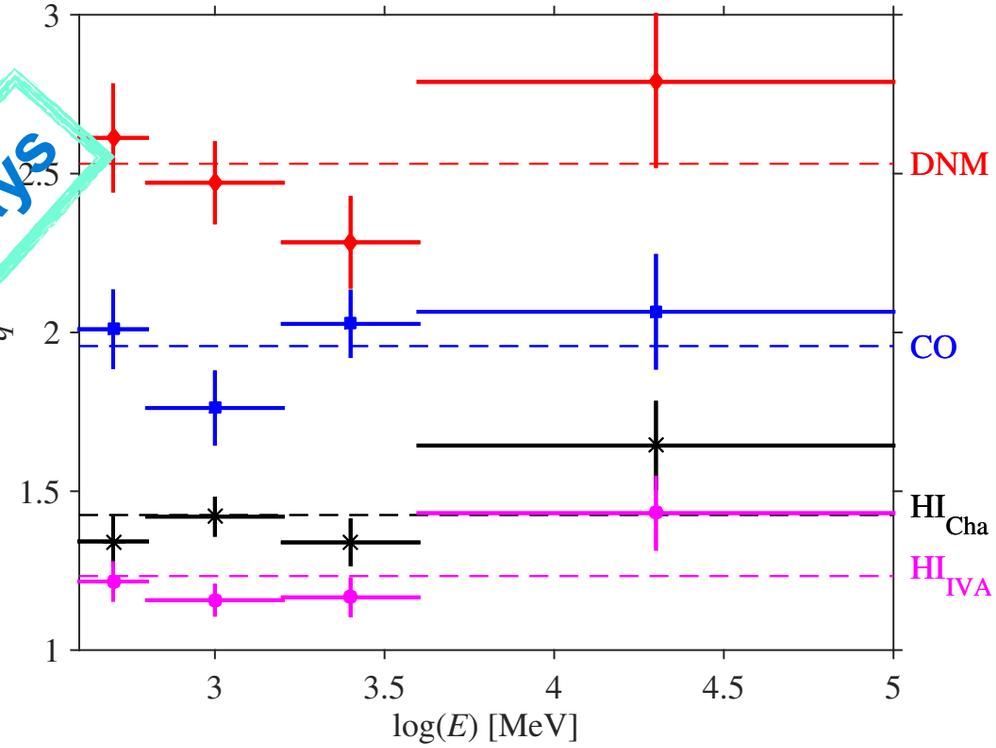


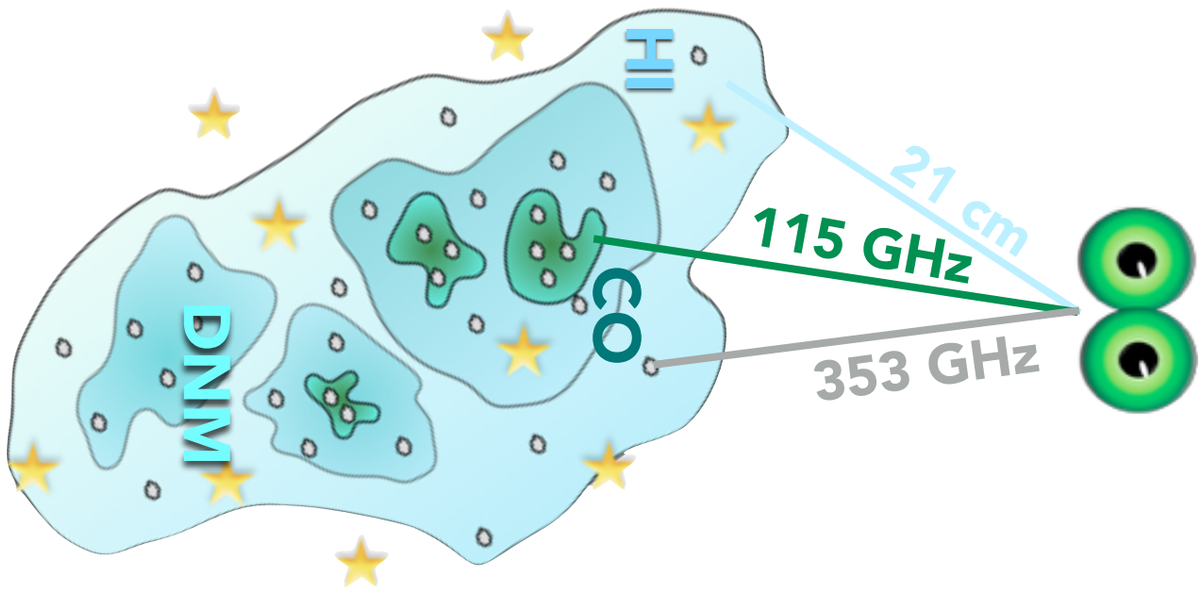
total gas tracing in γ rays

Planck+Fermi '15, A&A 582, 31



gas phases in the Chameleon

- DNM traced by CR & dust correlation
- DNM mass if same CR flux in the HI & DNM phases



- DNM spatial extent between the diffuse HI and compact CO

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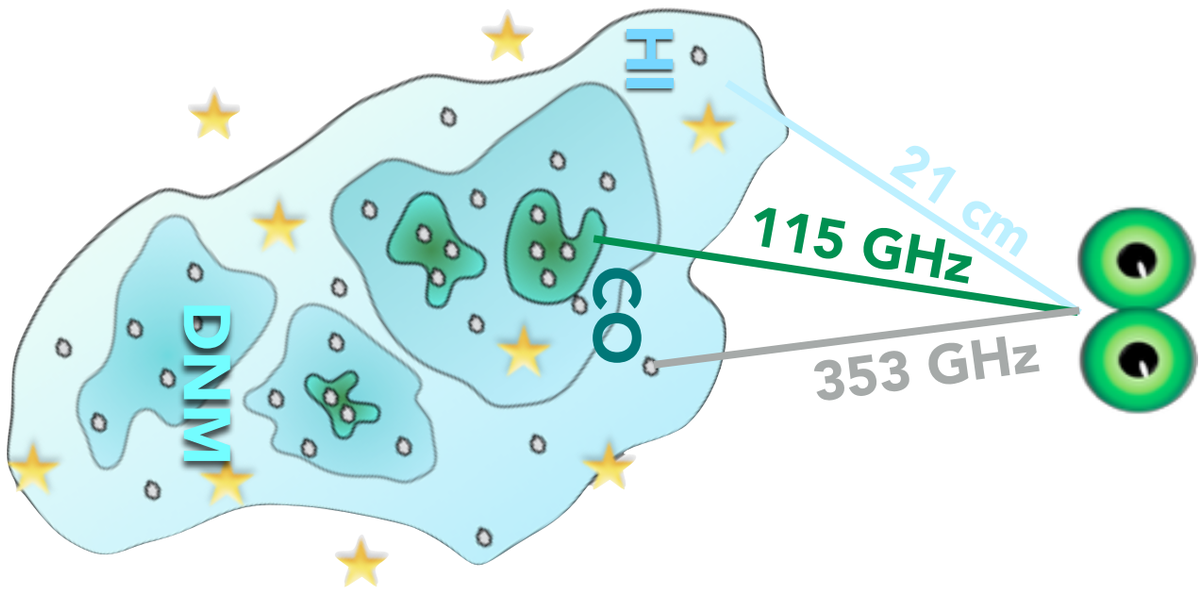

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gas phases in Taurus-Perseus-California

- M_{DNM} only assumption: $q_{HI} = q_{DNM}$
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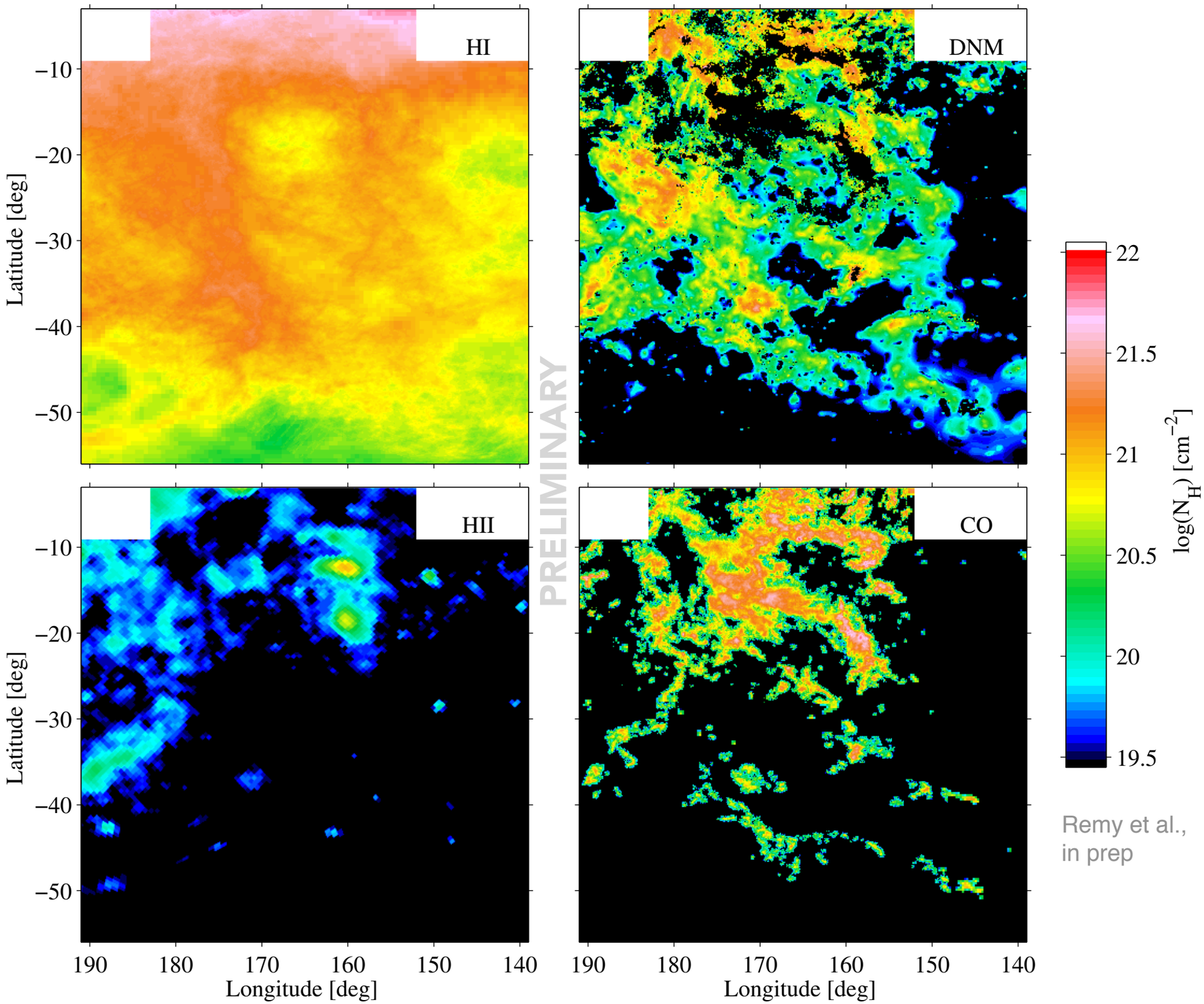

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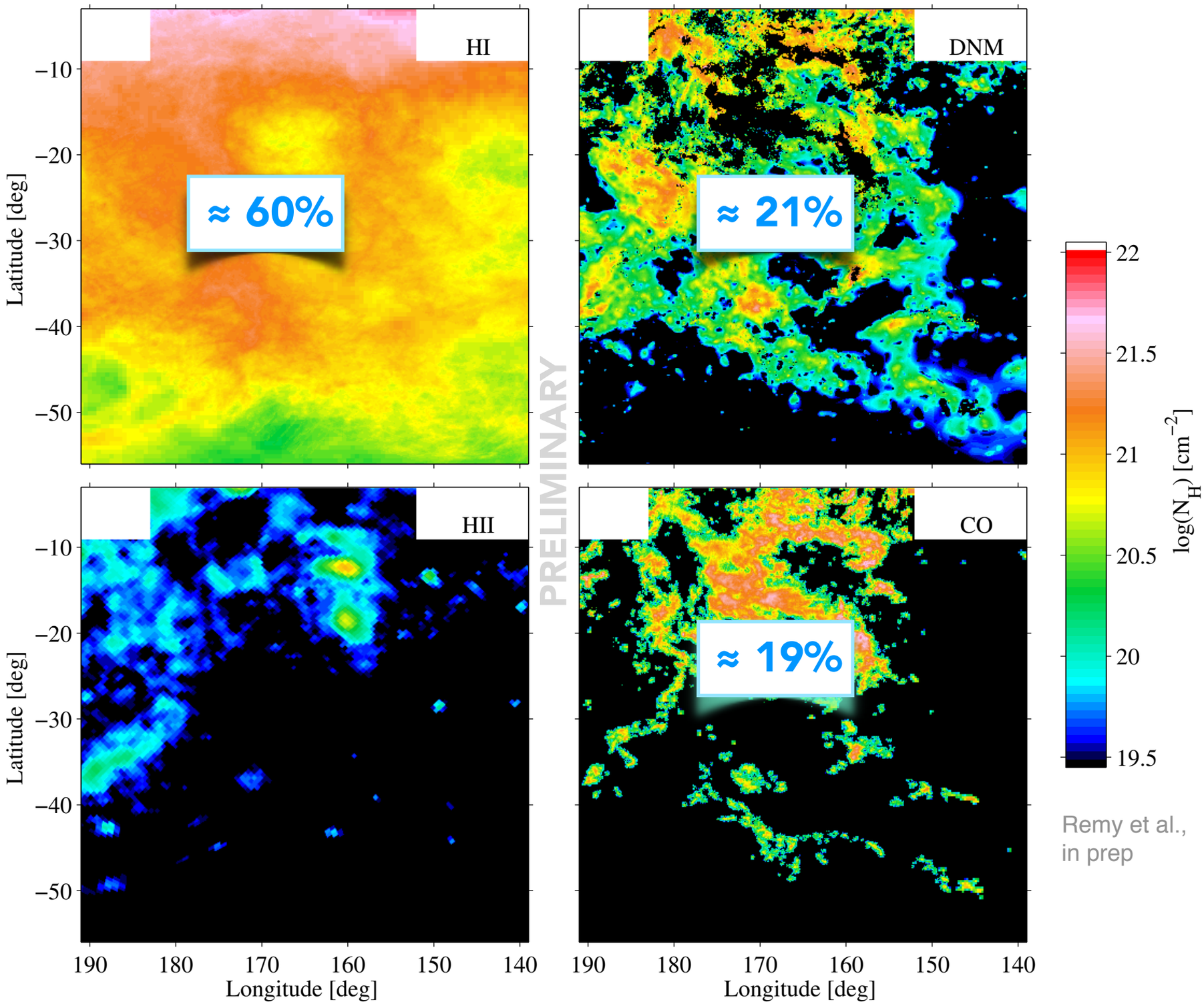

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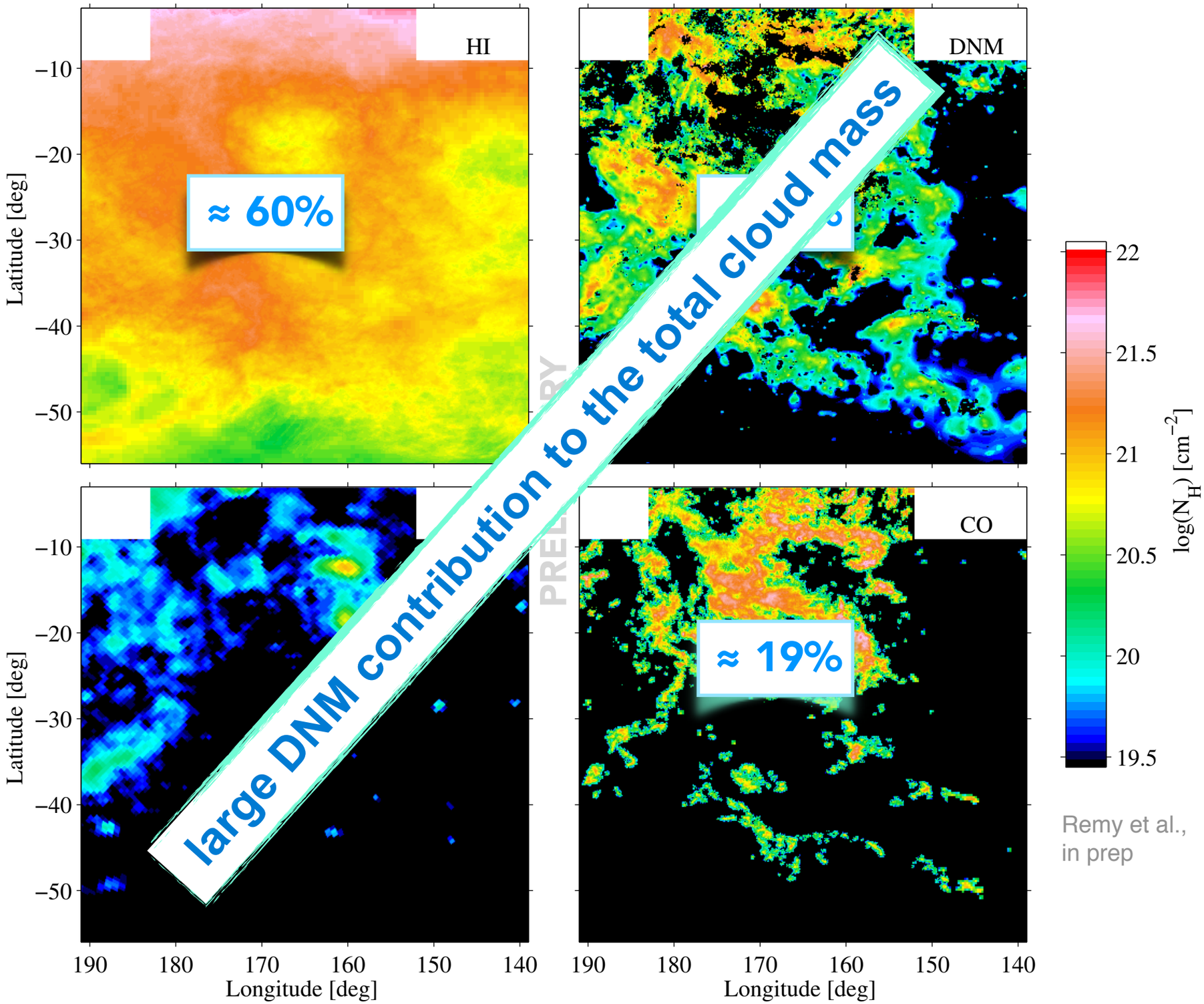
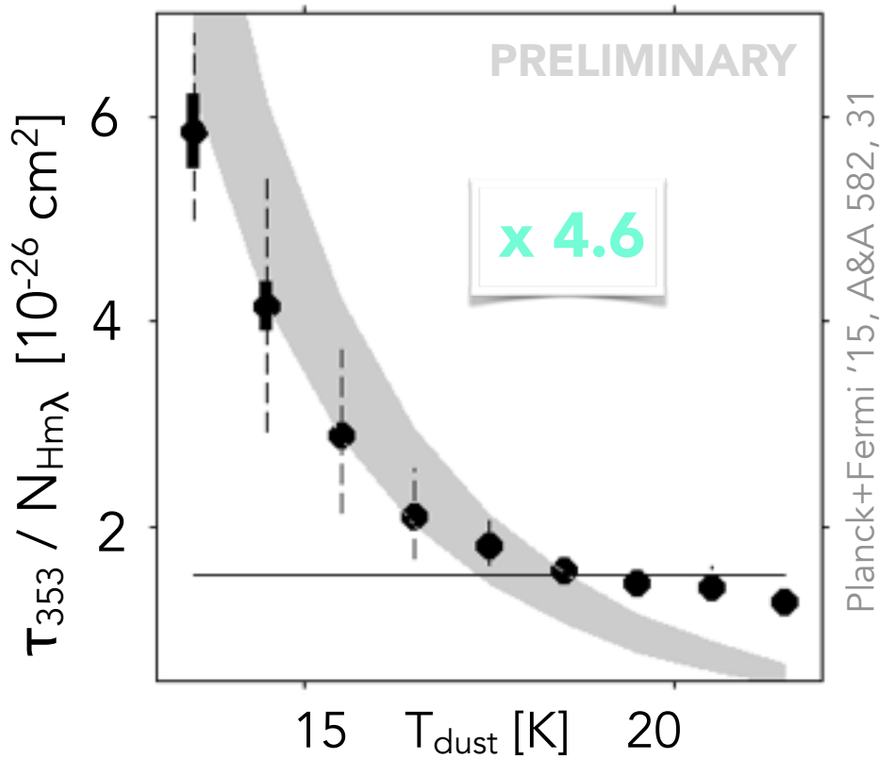


Remy et al., in prep

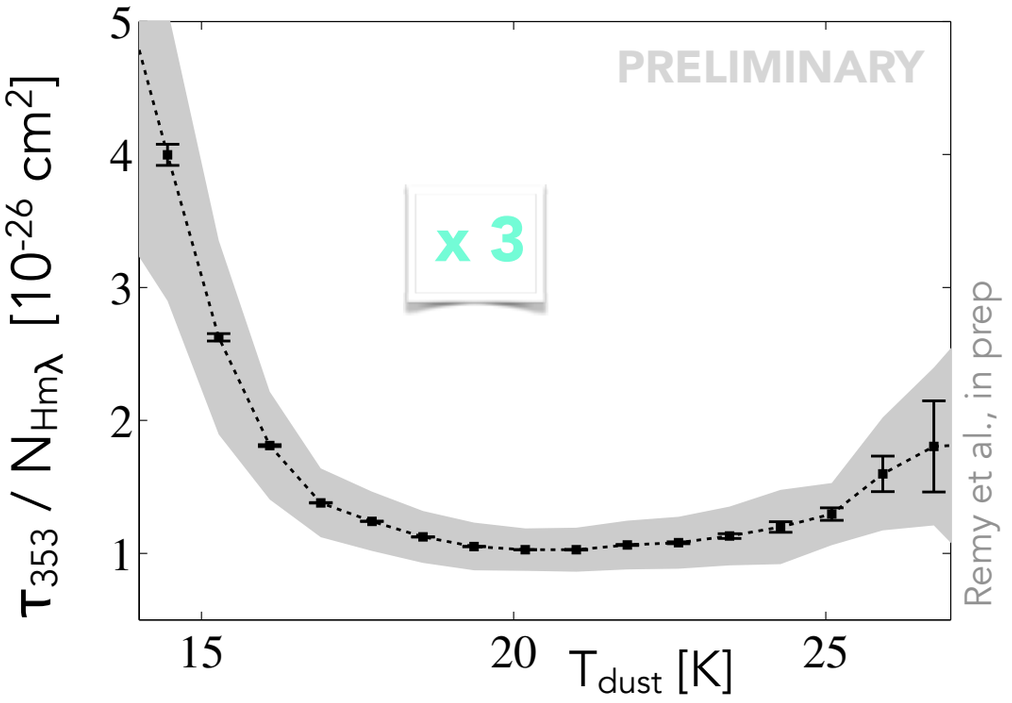
gas tracing with dust emission

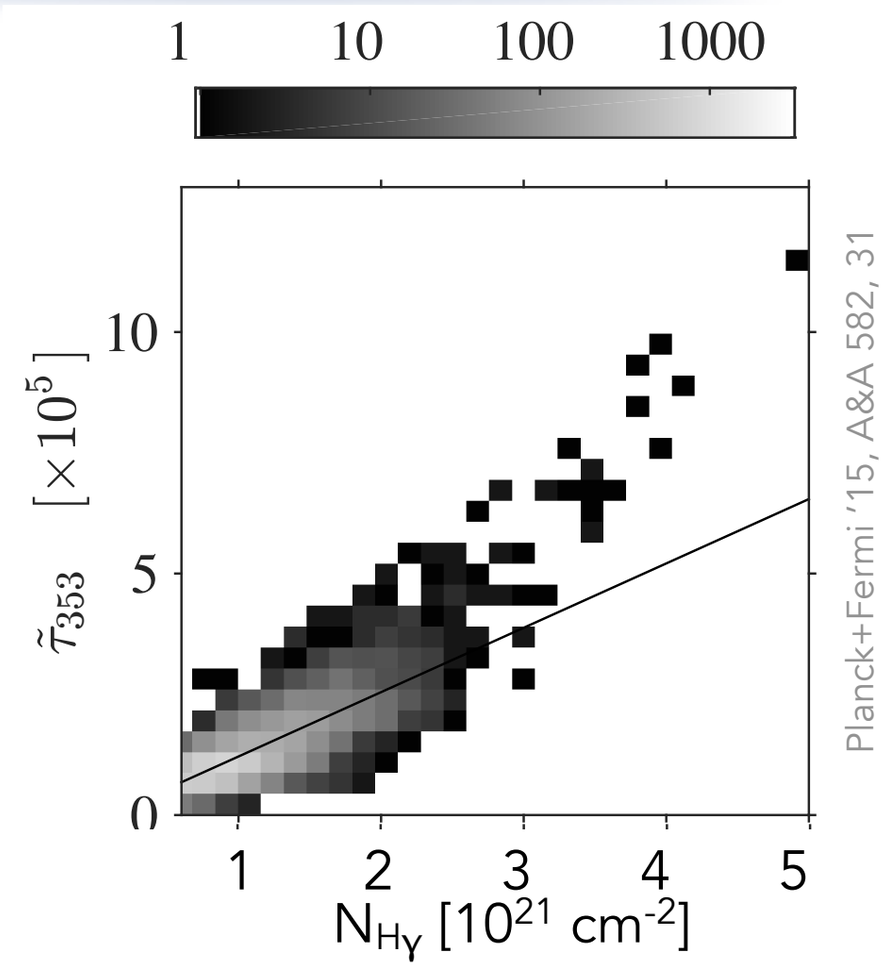
- significant increase in grain emission cross section
- grain evolution across all phases, more pronounced in CO

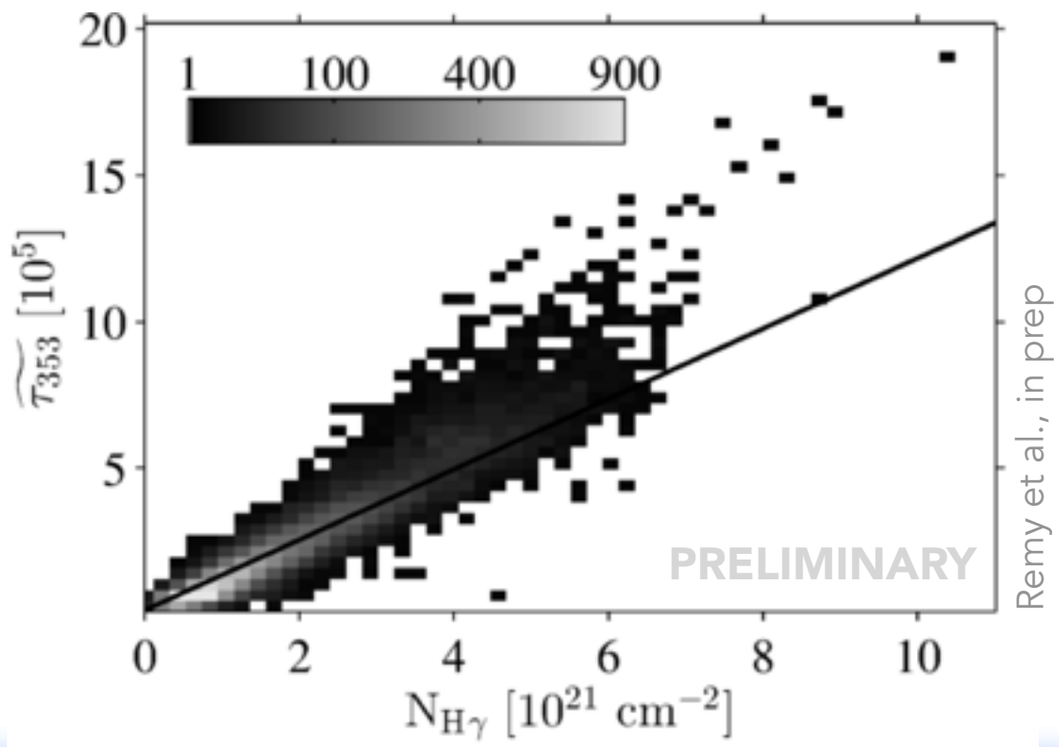


Chamaeleon

Taurus-Perseus-California







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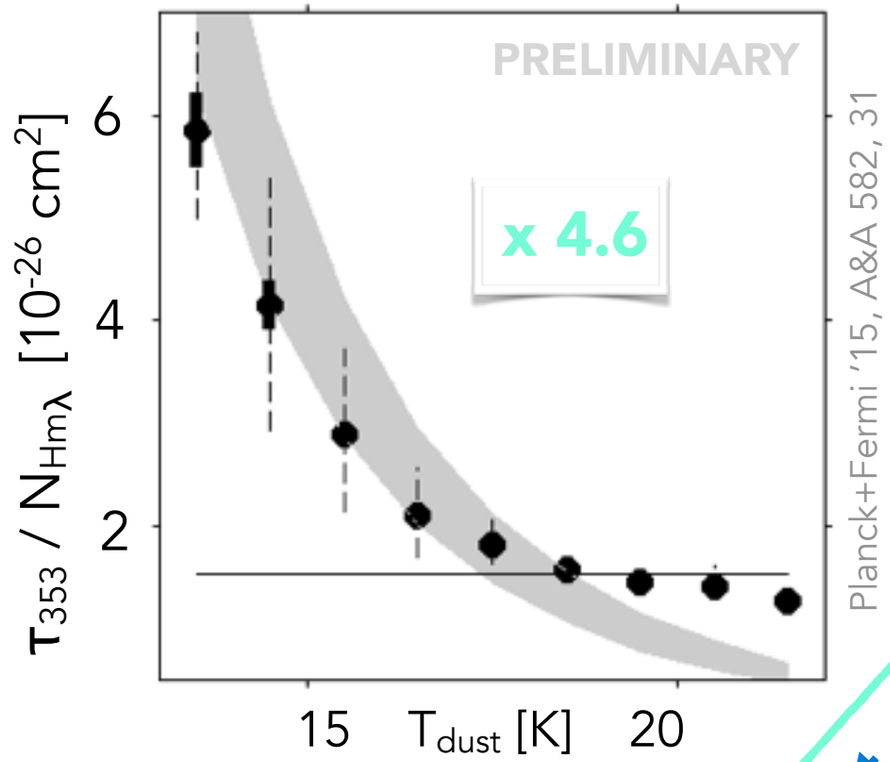
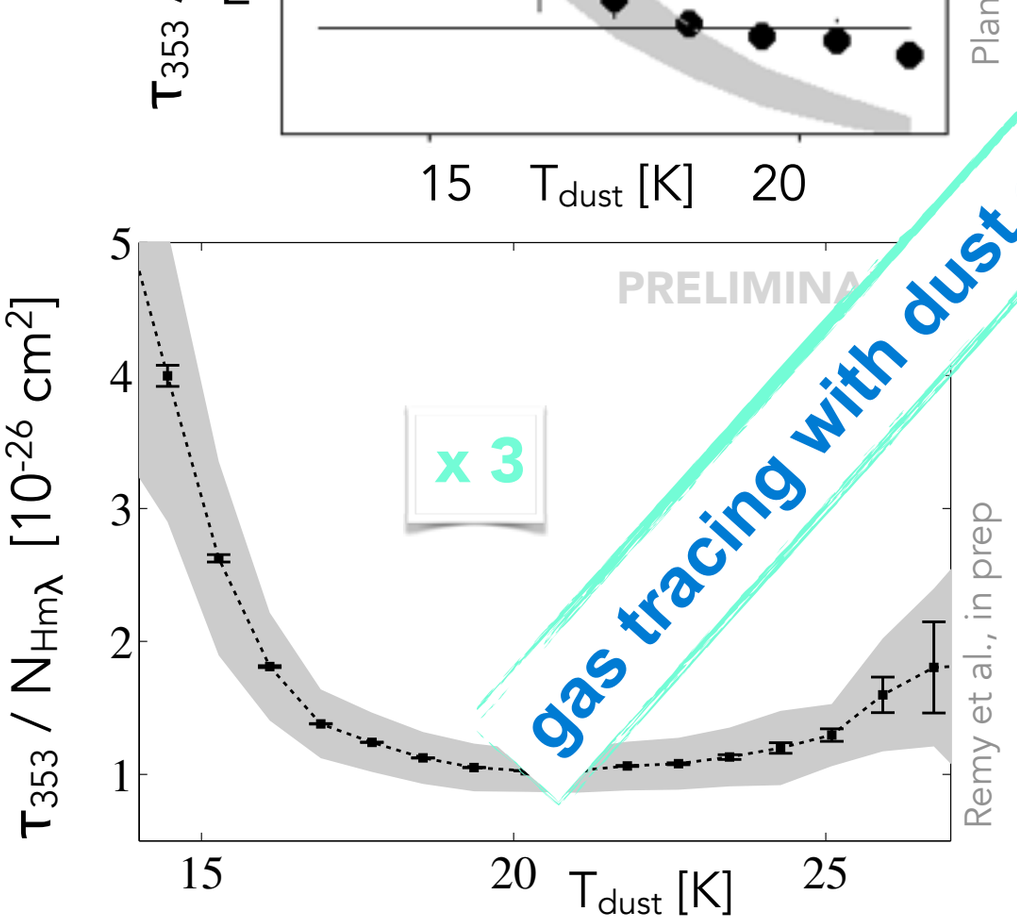
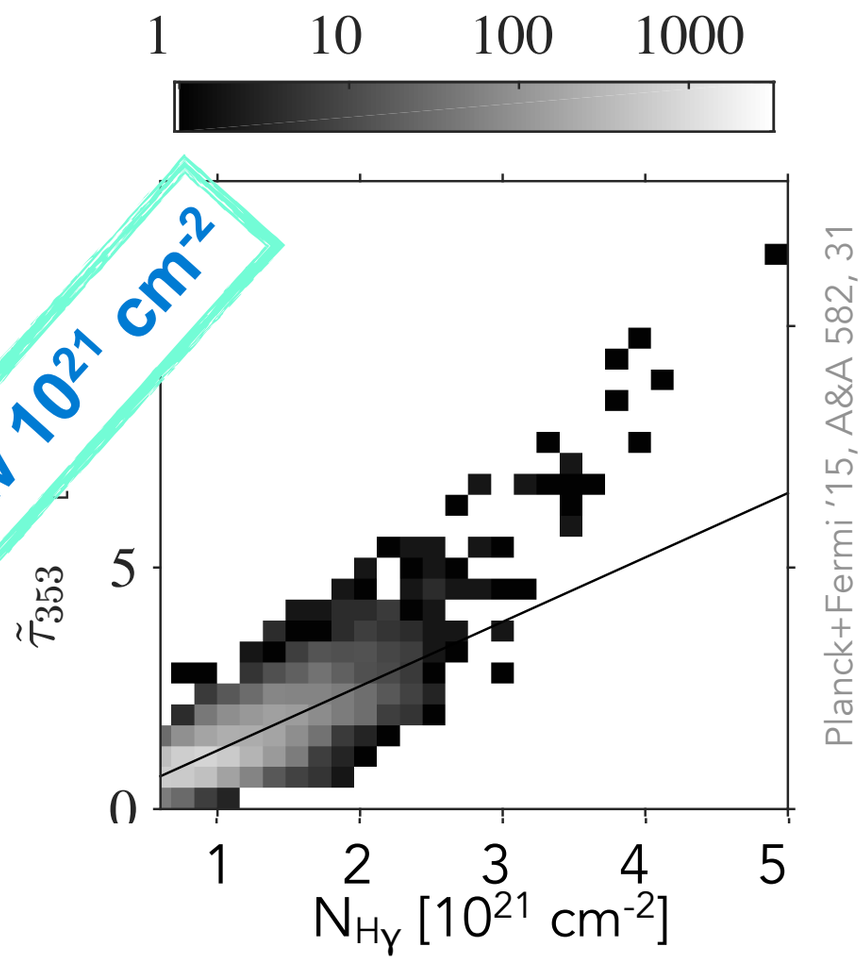


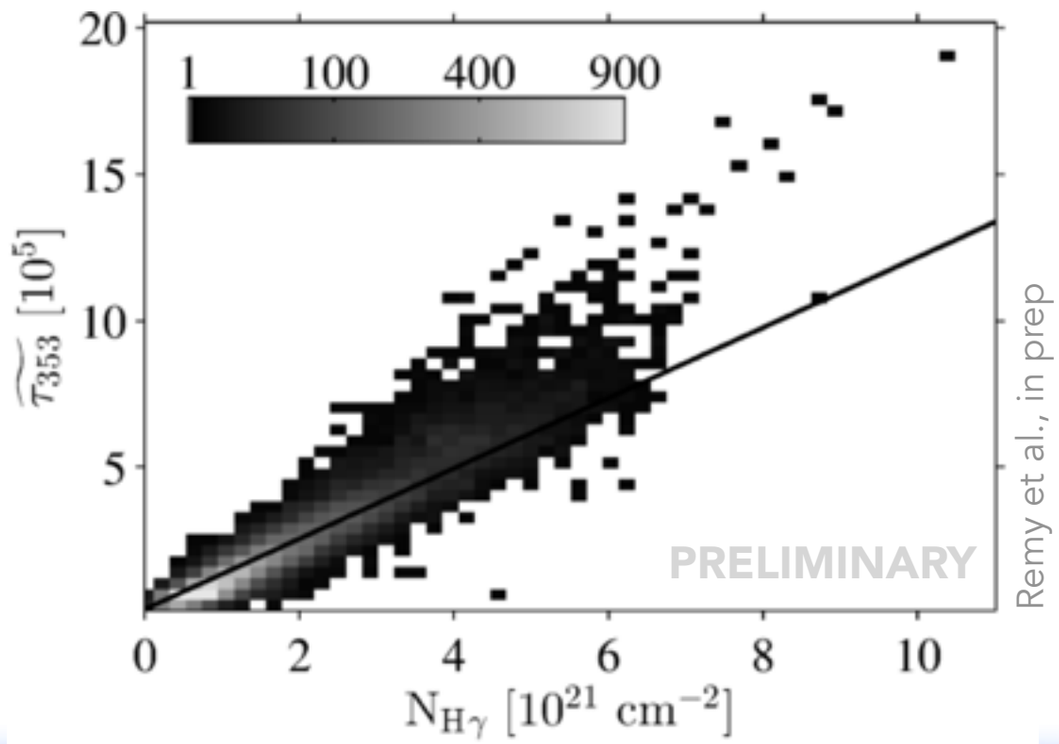


Chamaeleon

gas tracing with dust emission if N_H < few 10^{21} cm^{-2}

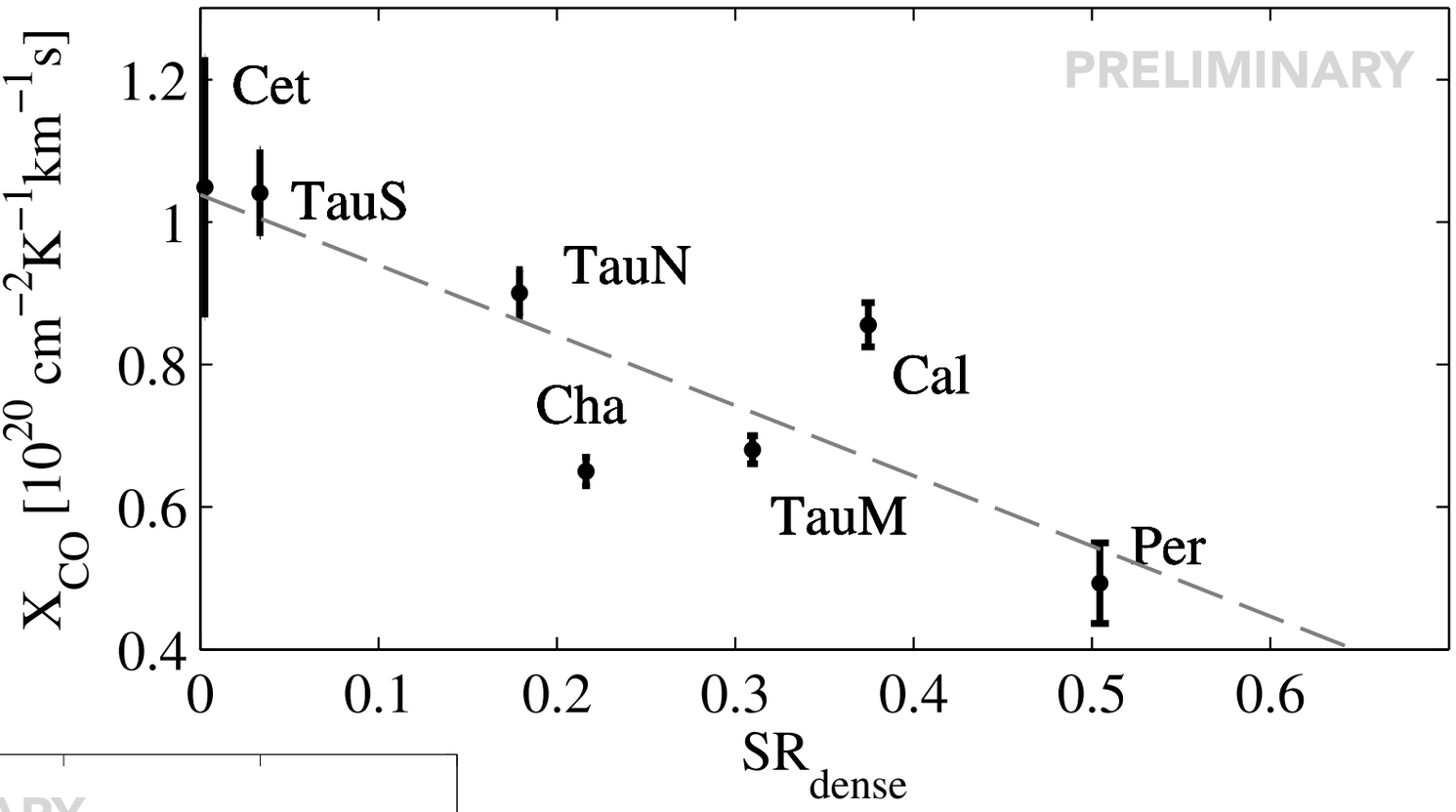
Taurus-Perseus-Californ

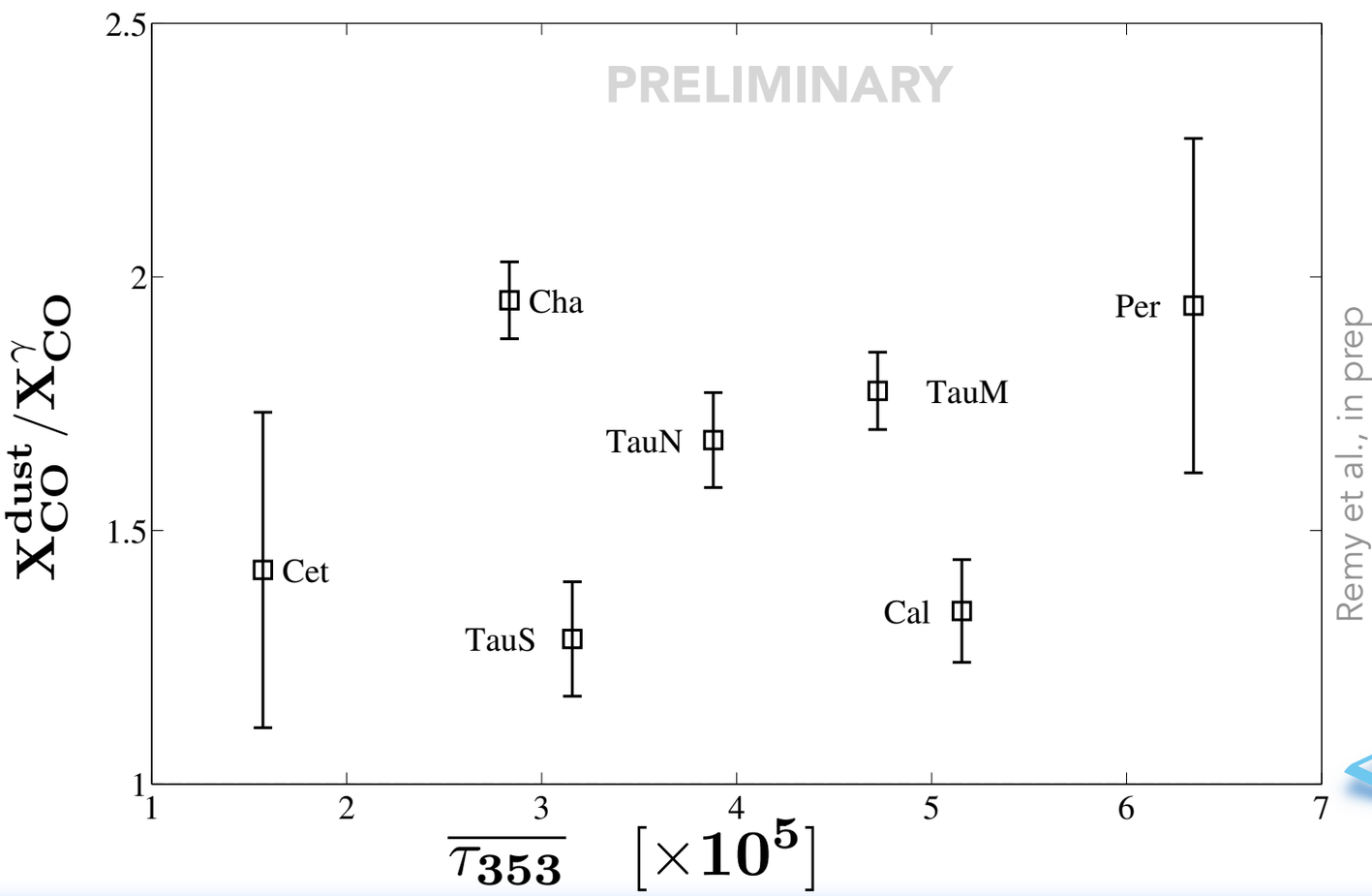




CO-to-H_2 conversion

- hints that X_{co} increases from dense cores to diffuse envelopes of the clouds
- X_{co}(dust) systematically larger then $X_{co}(\gamma)$ because of grain evolution in CO





$$SR_{dense} = \frac{S_{W_{CO}>7\,K\,km/s}}{S_{W_{CO}>1K\,km/s}}$$

1

in-depth study
of other clouds
underway

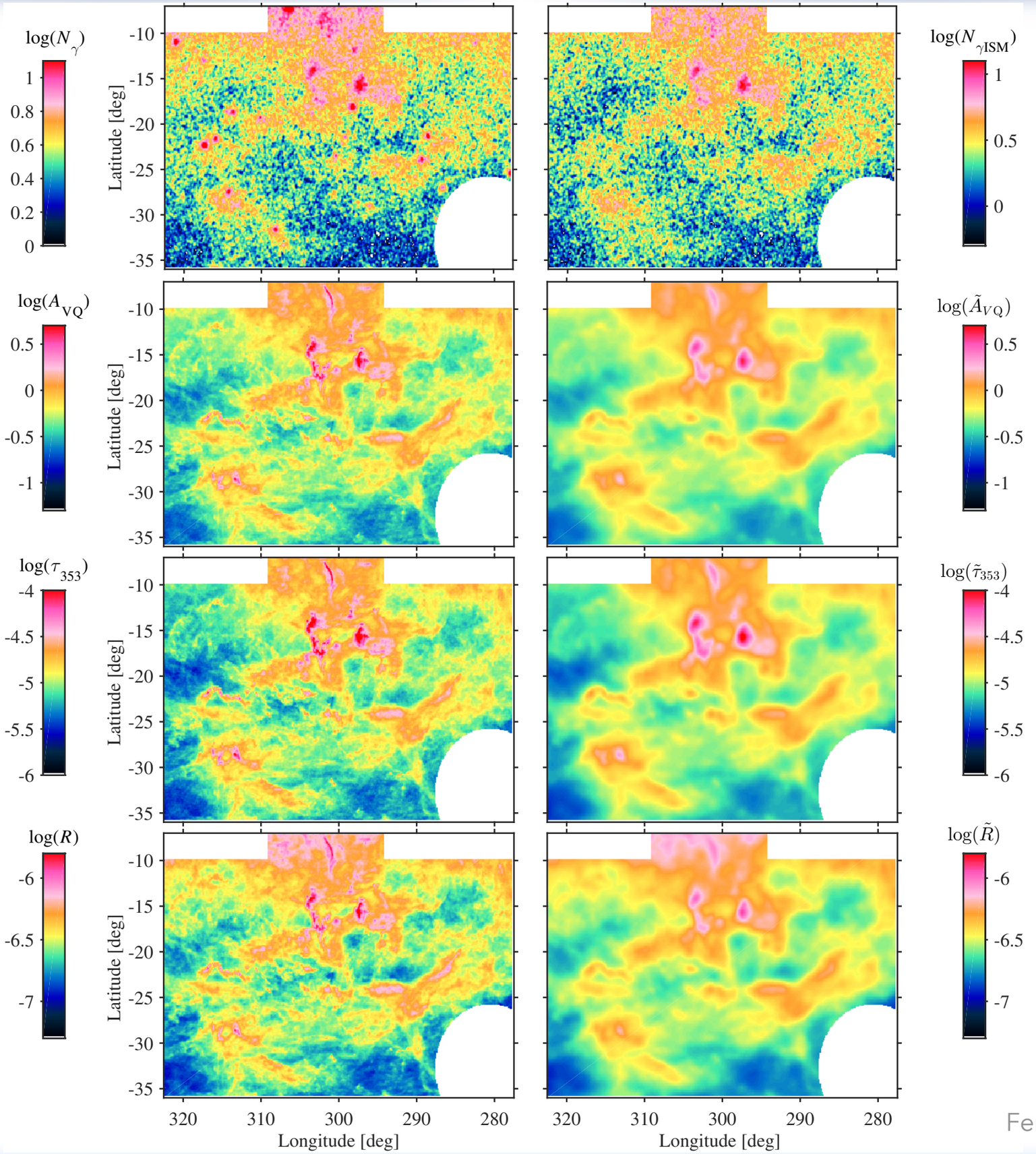
the Chameleon complex

LAT
0.4-100 GeV

modified dust
opt. depth

dust
opt. depth

dust
radiance

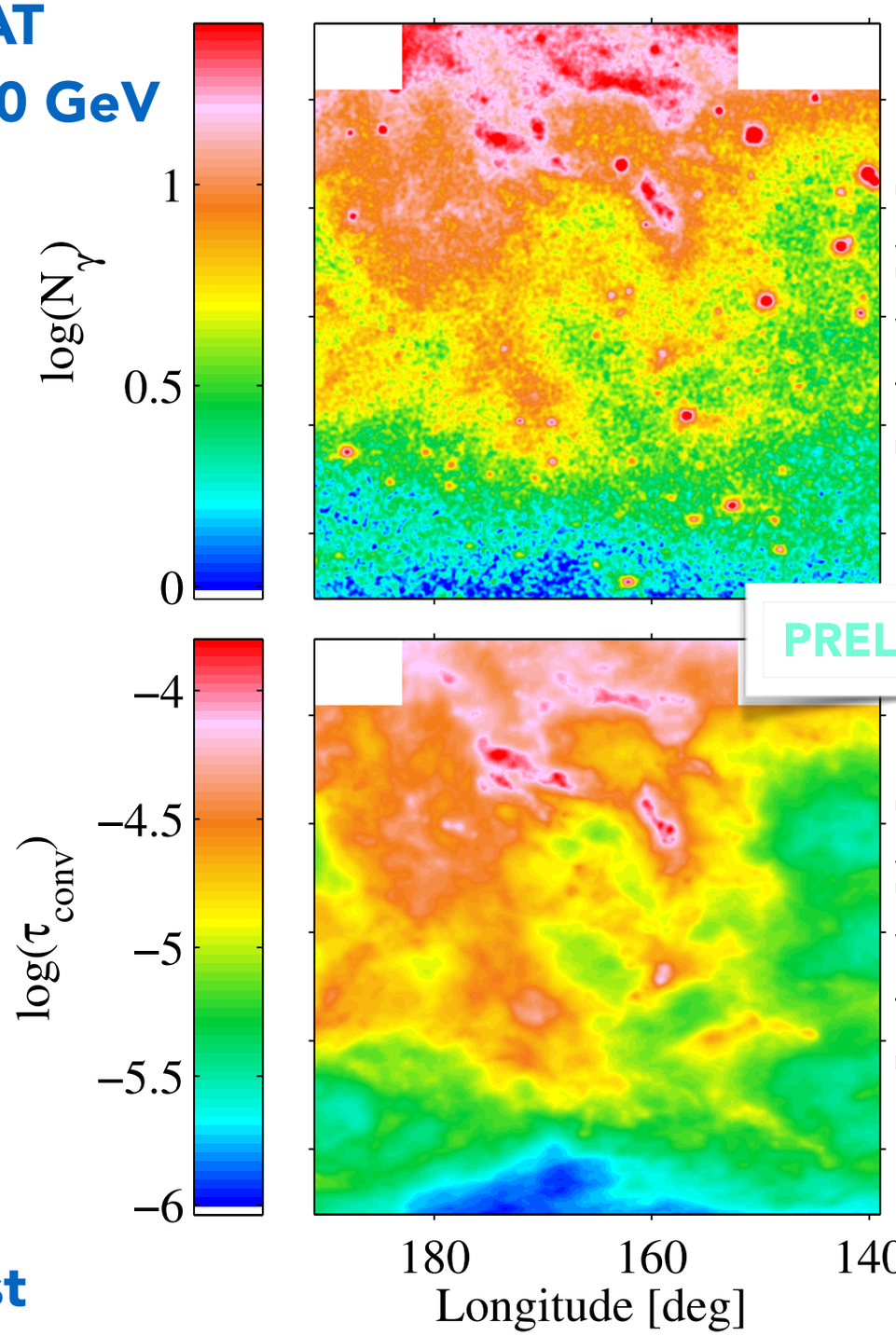


γ(ISM)
0.4-100 GeV

Fermi-Plaanck+ XXVIII, 2015

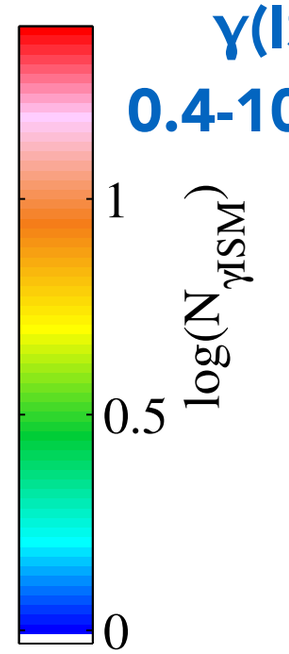
the Taurus complex

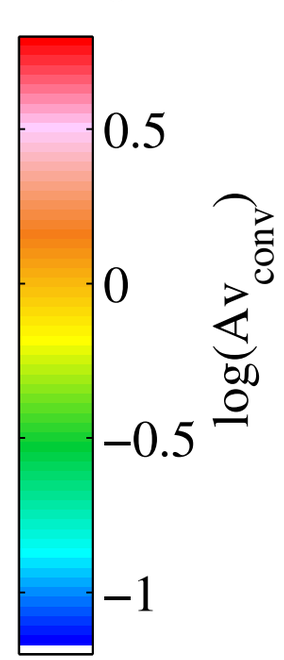
LAT
0.4-100 GeV



PRELIMINARY

γ(ISM)
0.4-100 GeV





dust
opt. depth

modified dust
opt. depth

γ-ray and dust modelling

- CRays in HI: N(HI)

$$\frac{\mathbf{dN_{CR}}}{\mathbf{dV}}$$

- CRays in H_2:

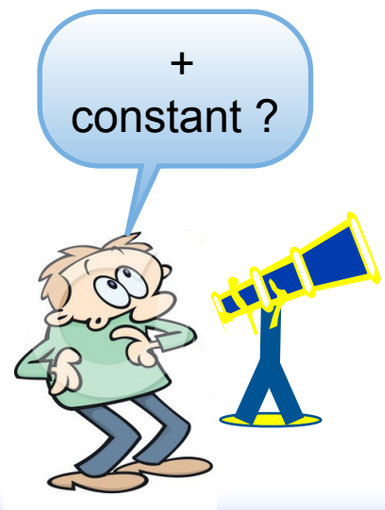
$$\mathbf{X_{CO}} = \frac{\mathbf{N(H_2)}}{\mathbf{W(CO)}}$$

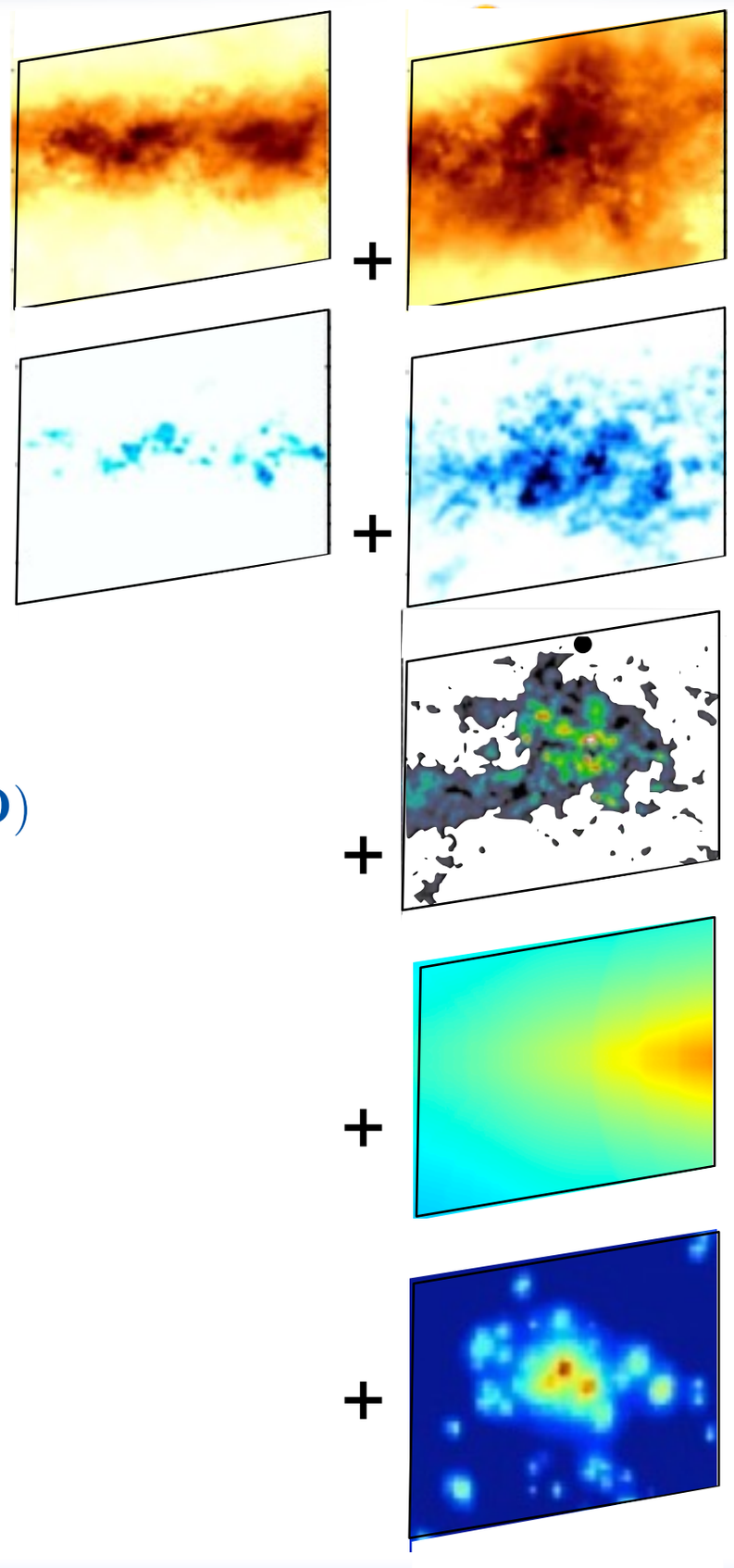
- CRays in dark neutral gas:

$$\mathbf{I_\gamma - a\,N(HI) - b\,W(CO)}$$

- Galactic inverse Compton

- γ-ray source





dust in HI

$$\frac{\tau_{\mathbf{dust}}}{\mathbf{NH}}$$

dust in H_2

$$\mathbf{X_{CO}} = \frac{\mathbf{N(H_2)}}{\mathbf{W(CO)}}$$

dust in dark neutral gas

$$\tau_{\mathbf{dust}} - \mathbf{a'\,N(HI) - b'\,W(CO)}$$

CIB + CMB

IR sources

γ-ray and dust modelling

- CRays in HI: N(HI)

$$\frac{dN_{CR}}{dV}$$

dust in HI

$$\frac{\tau_{dust}}{NH}$$

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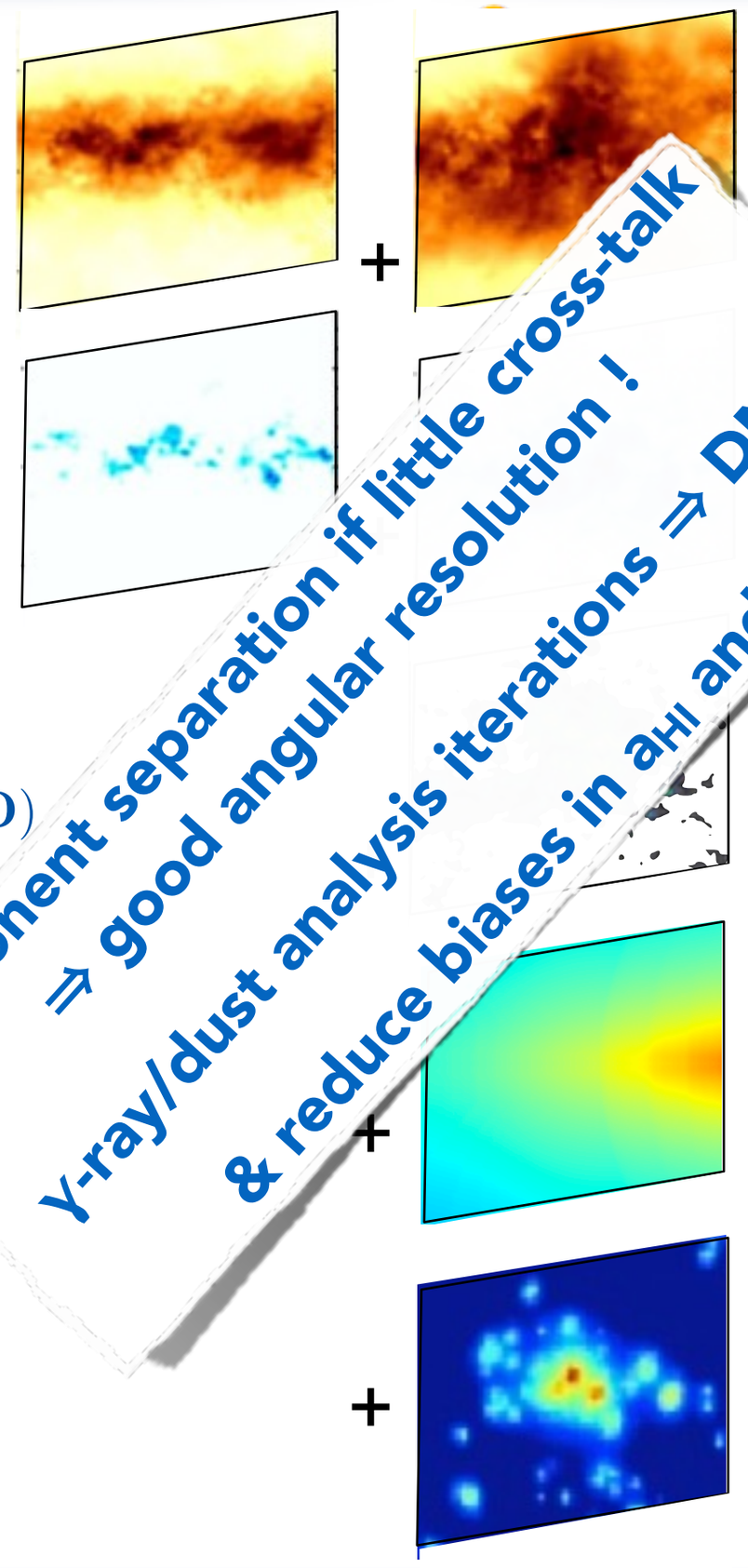
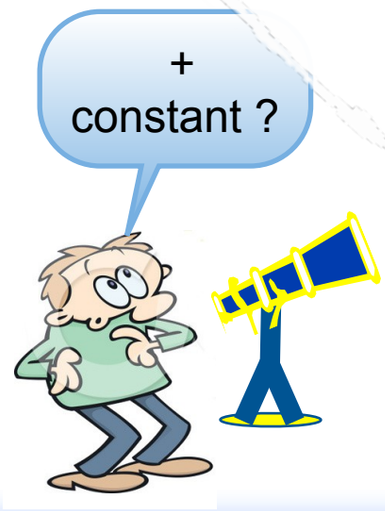


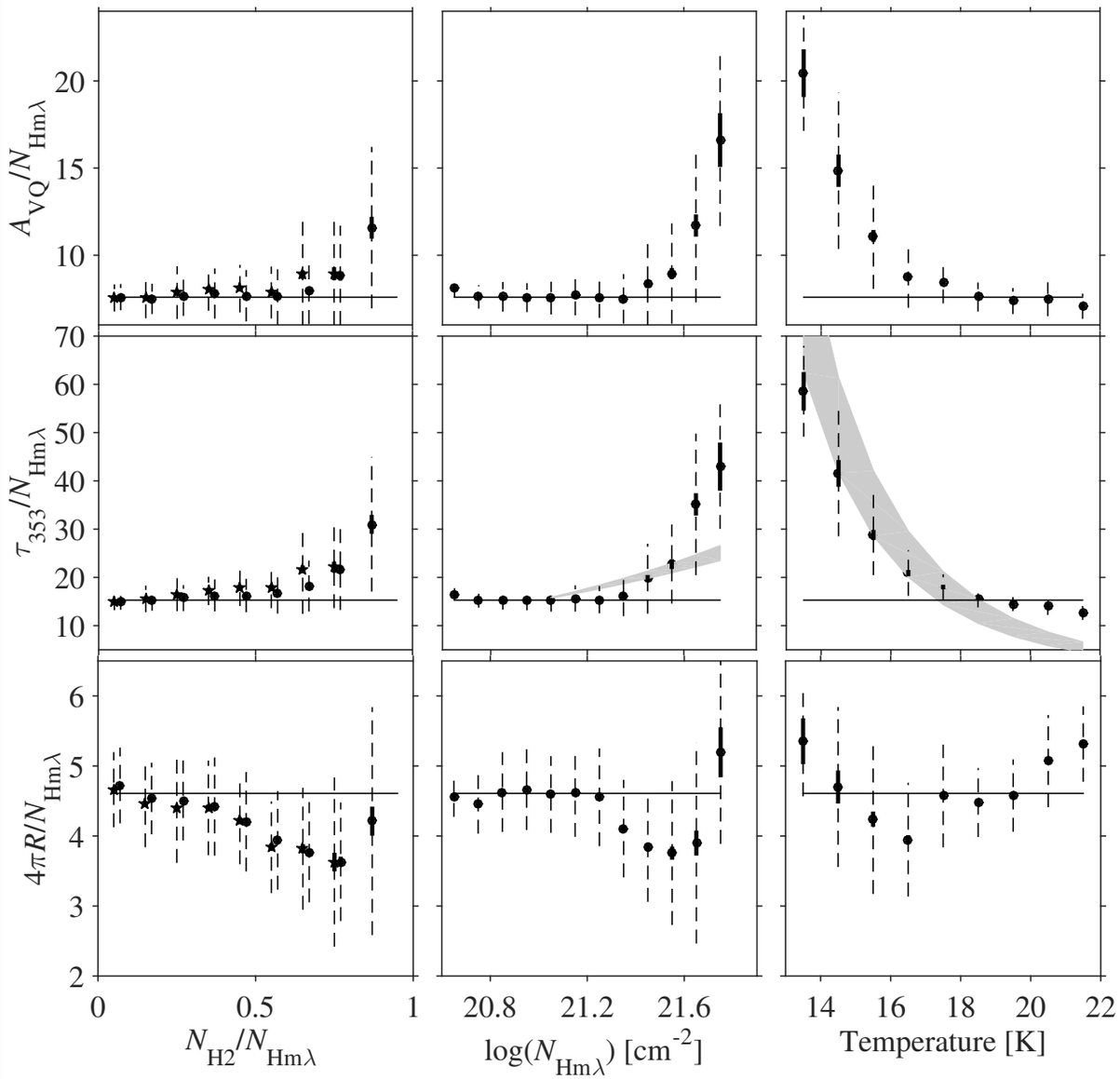
component separation if little cross-talk
⇒ good angular resolution !
γ-ray/dust analysis iterations ⇒ DNM
& reduce biases in a_{HI} and b_{CO}

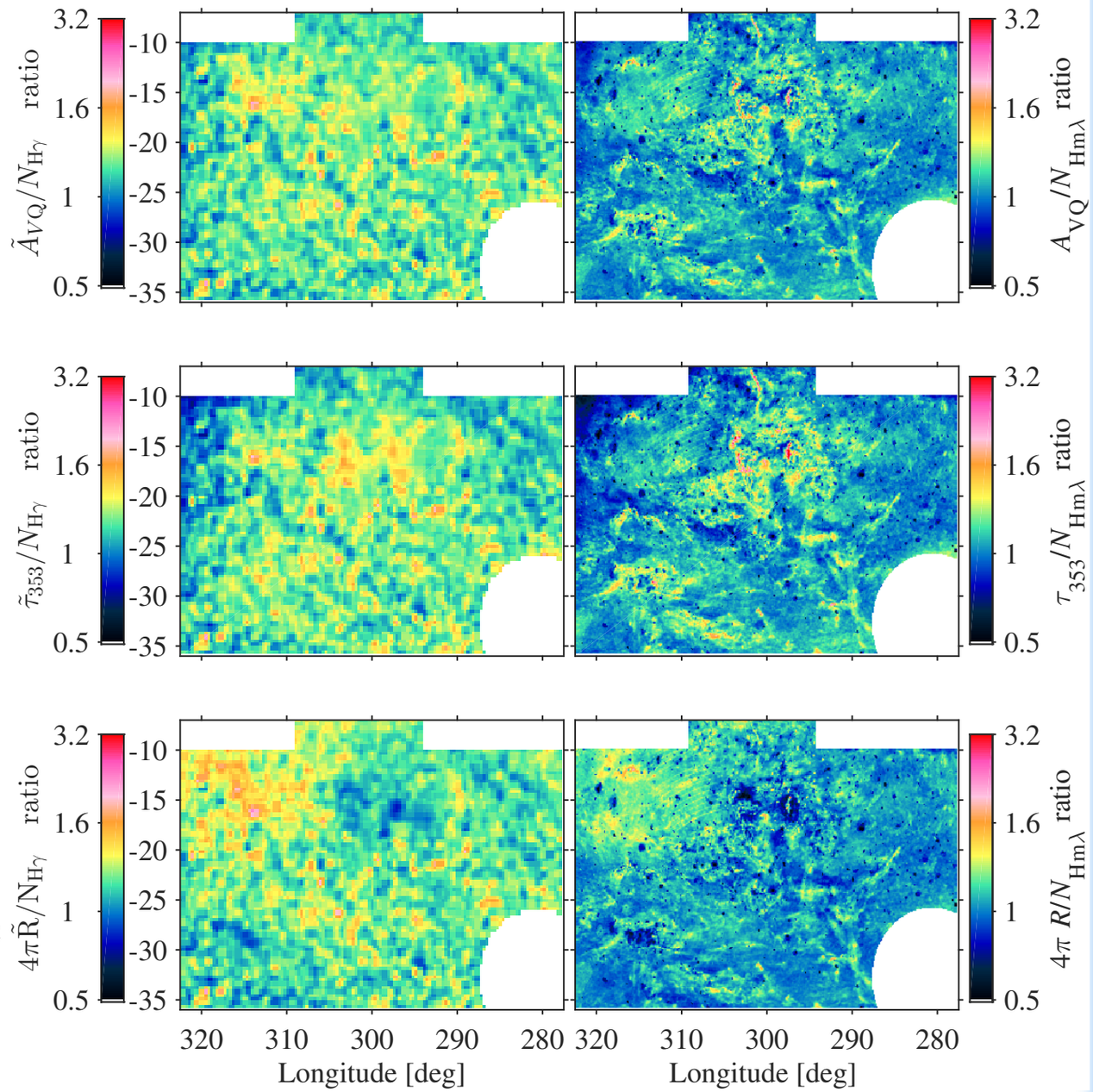


dust evolution in the Chameleon complex

- average $\tau_{353}/N_H \approx$ (2-3) times the all-sky average, twice the HI cirrus value
- 2 to 4.6-fold rise in τ_{353}/N_H and 1.5 to 2.9-fold rise in A_{VQ}/N_H over a single decade in N_H
  - ✦ albeit 2-fold decline in radiated power
  - ✦ opacity rise related to increase in density and H_2 fraction
  - ✦ peaks in CO because of opt. thick ^{12}CO

$$NH_{m\lambda} = N_{HI} + 2*X_{co\gamma} * W_{CO} + NH_{DNM\gamma}$$





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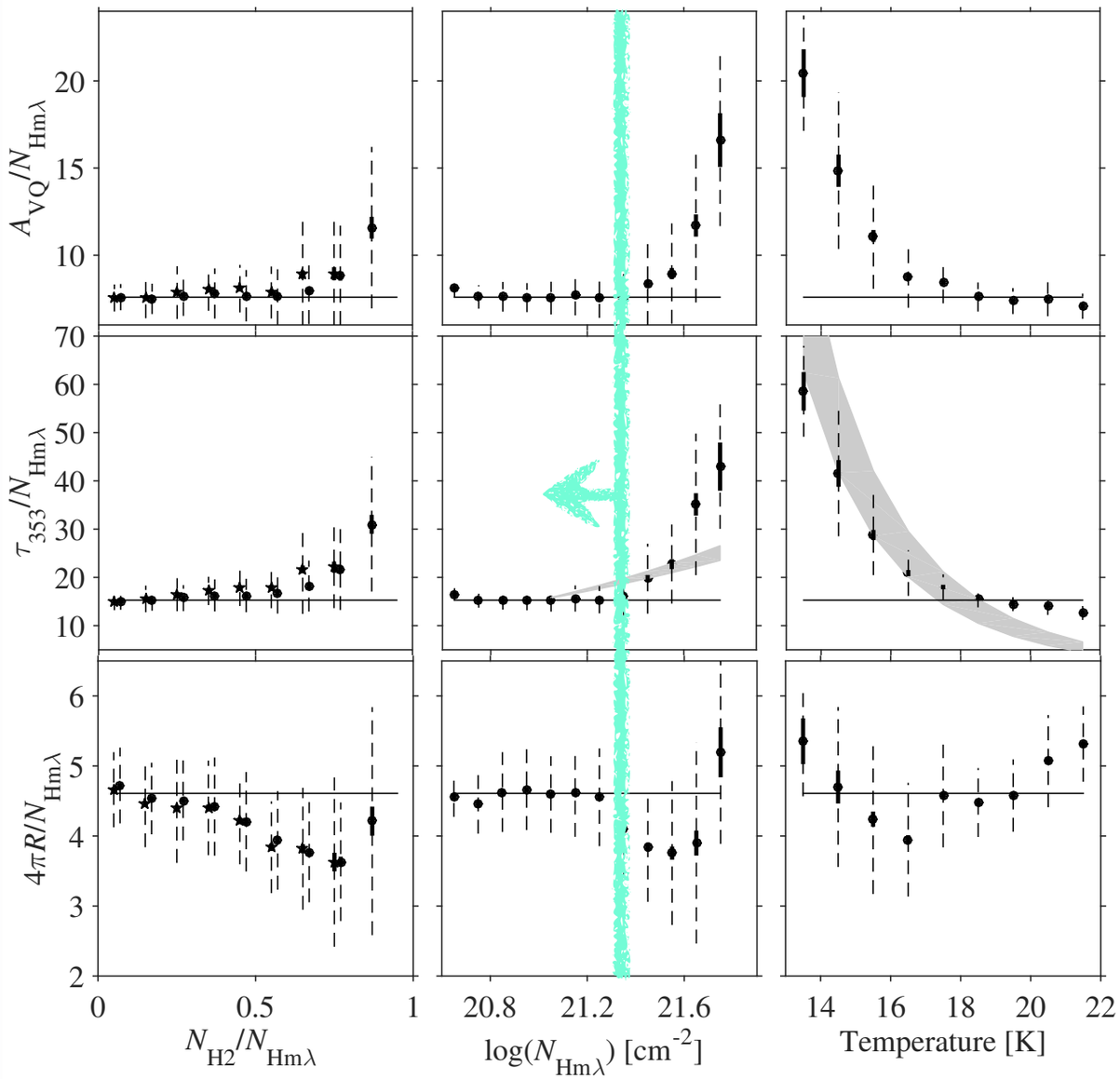

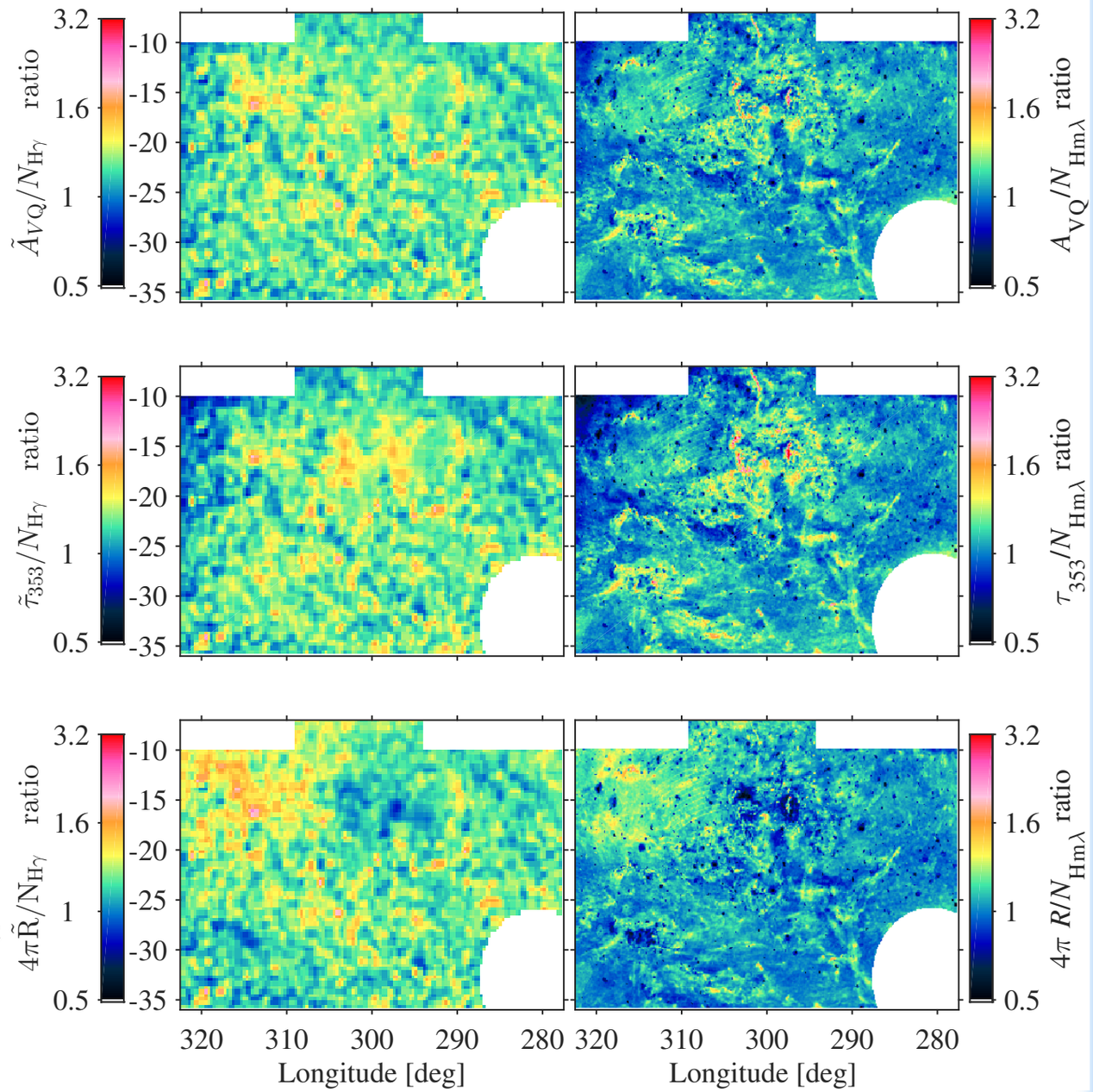

gas tracing by dust if NH < 2 10^{21} cm^{-2}

dust evolution in the Taurus complex

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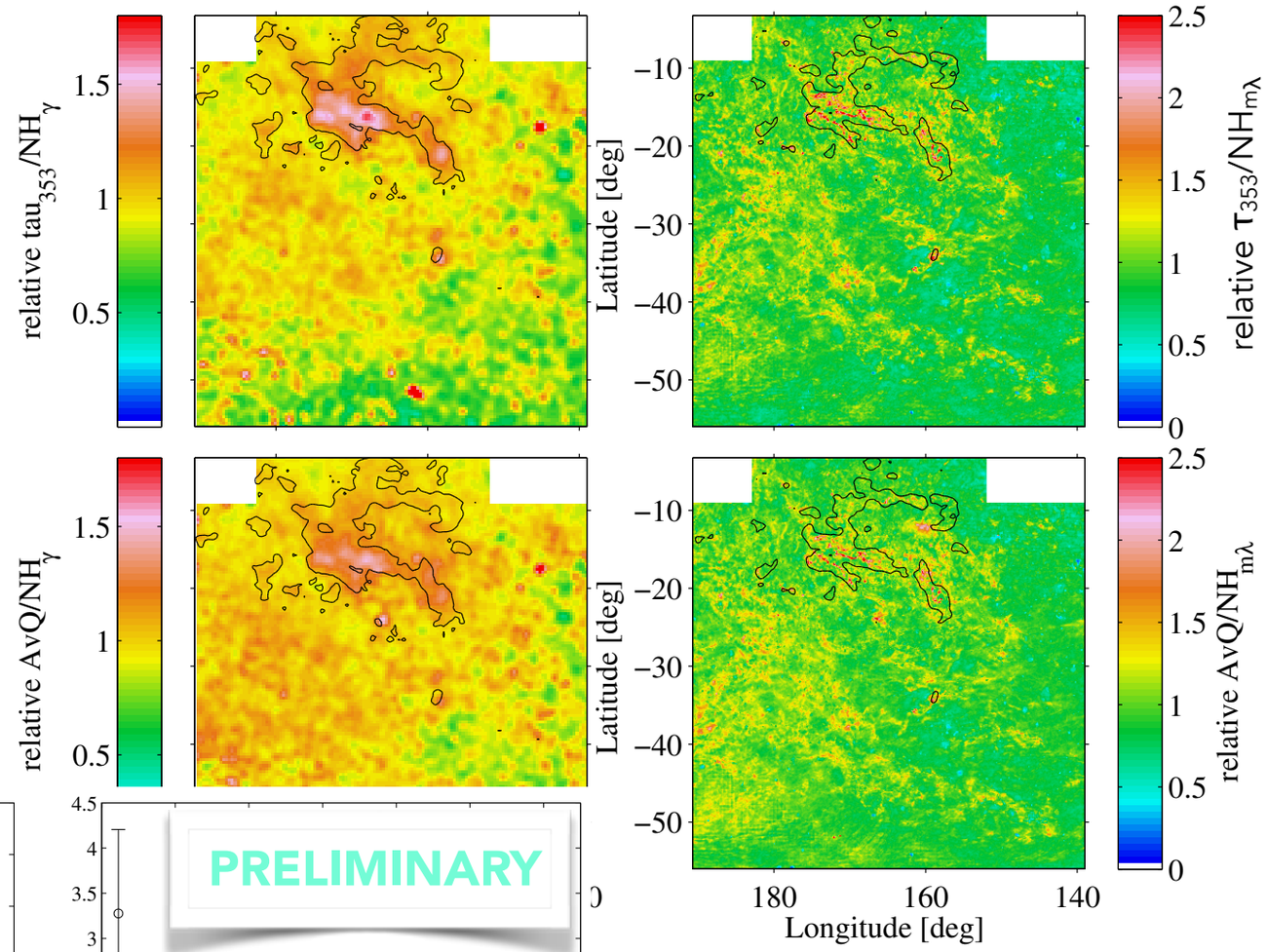

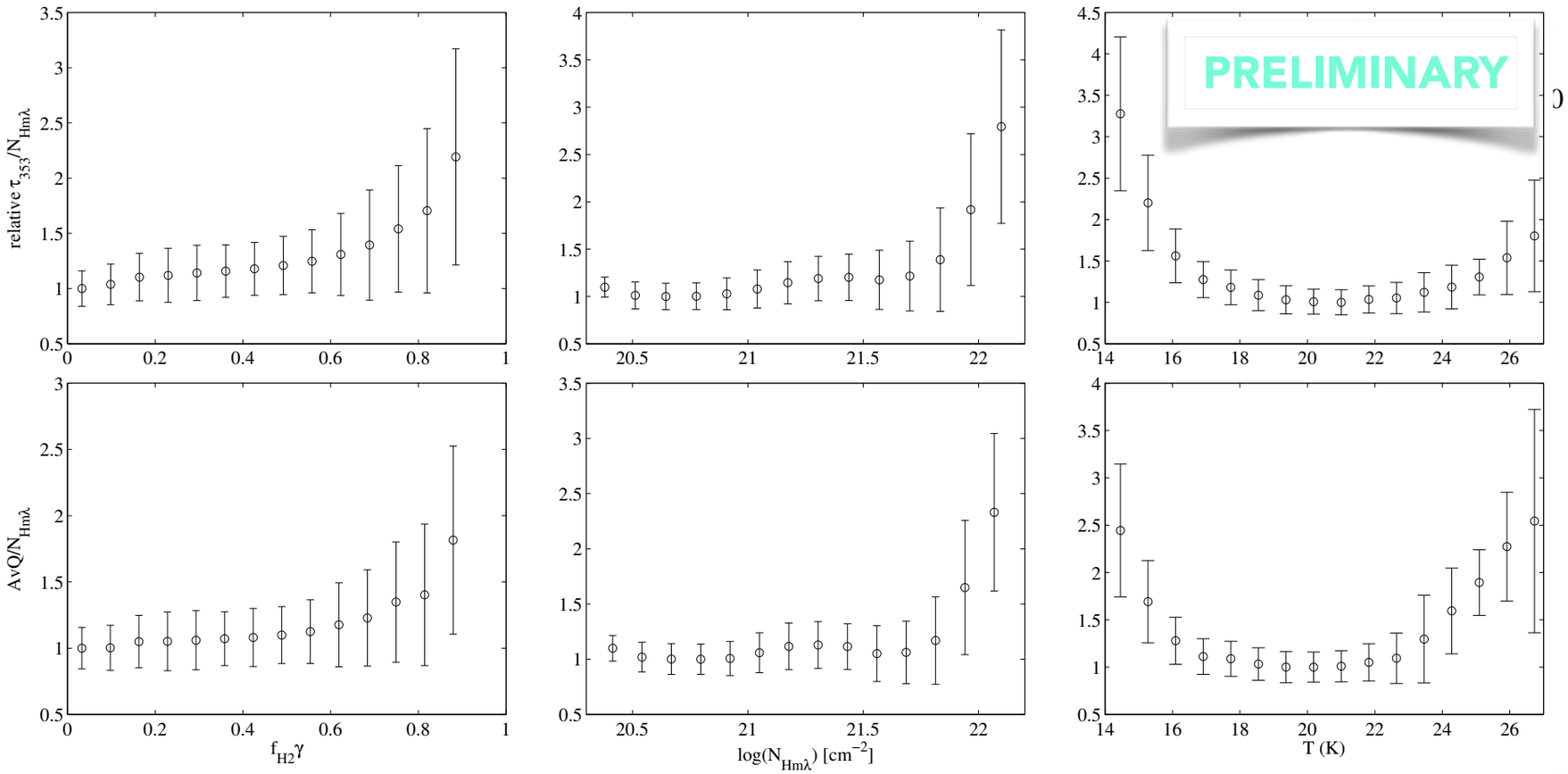

dust evolution in the Taurus complex

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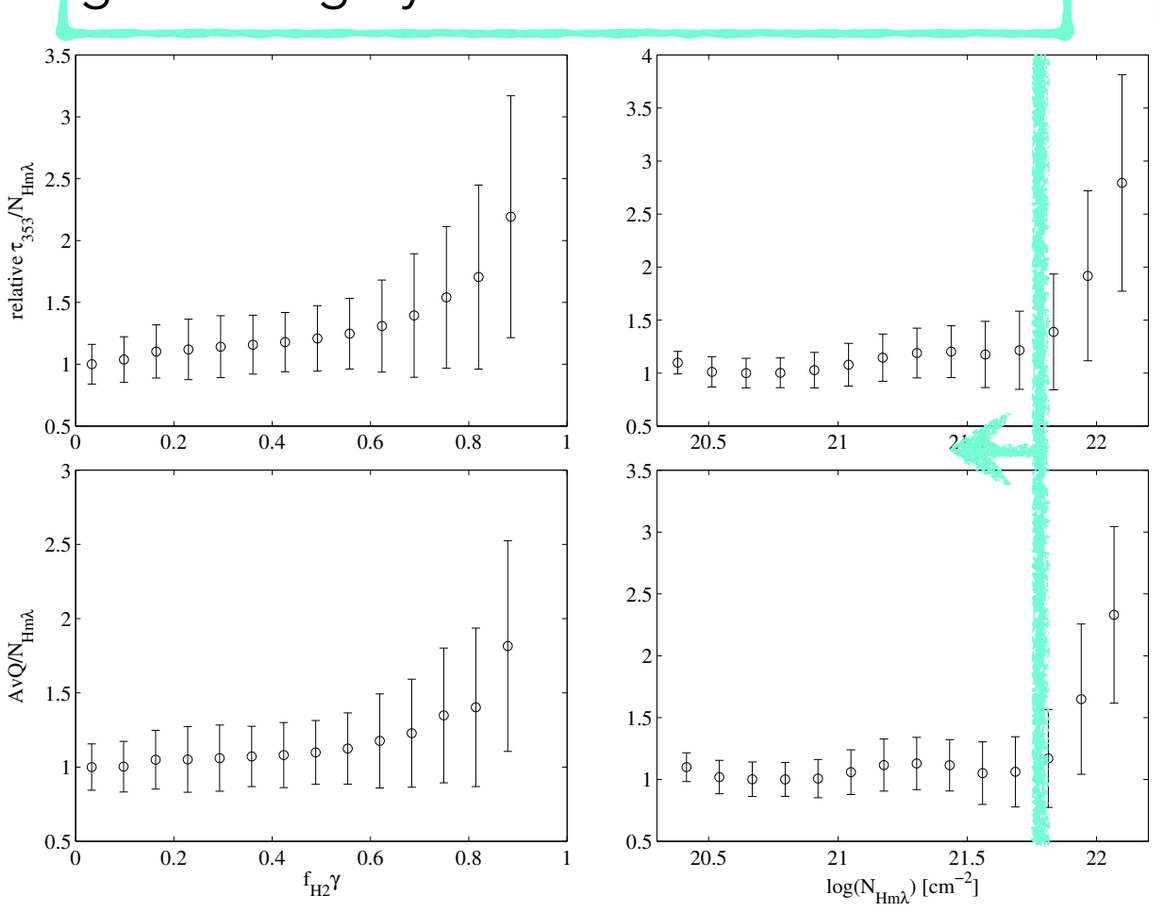
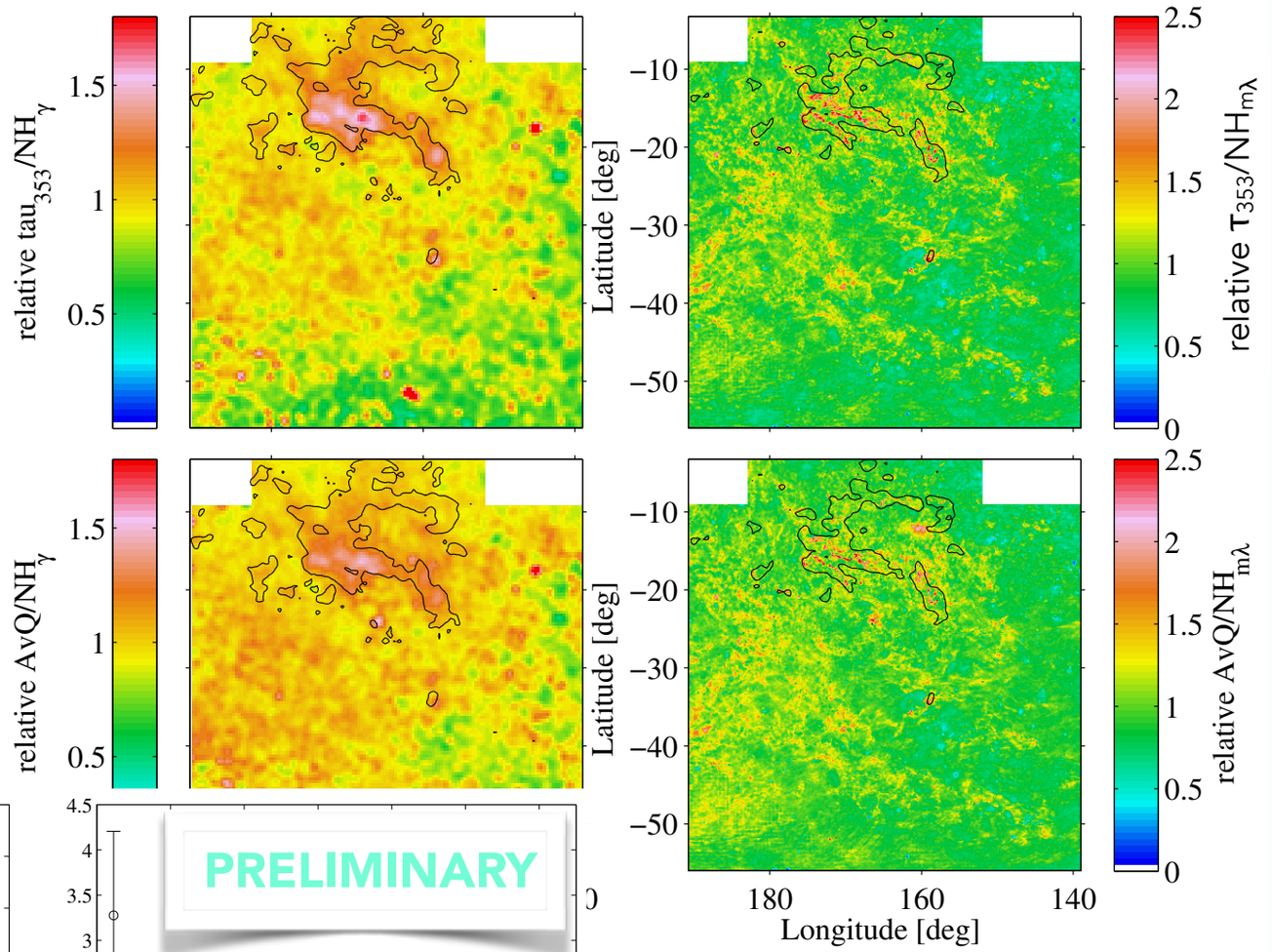
gas tracing by dust if NH < 5 10^{21} cm^{-2}

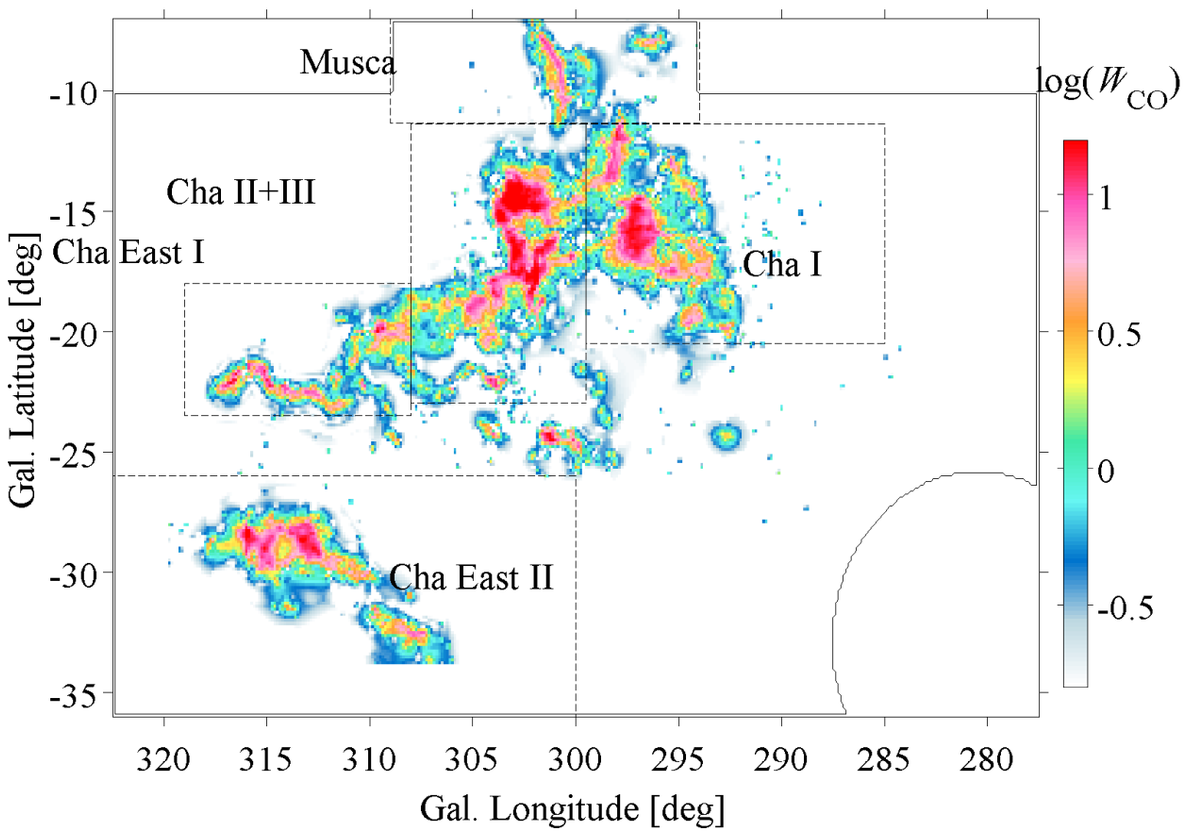


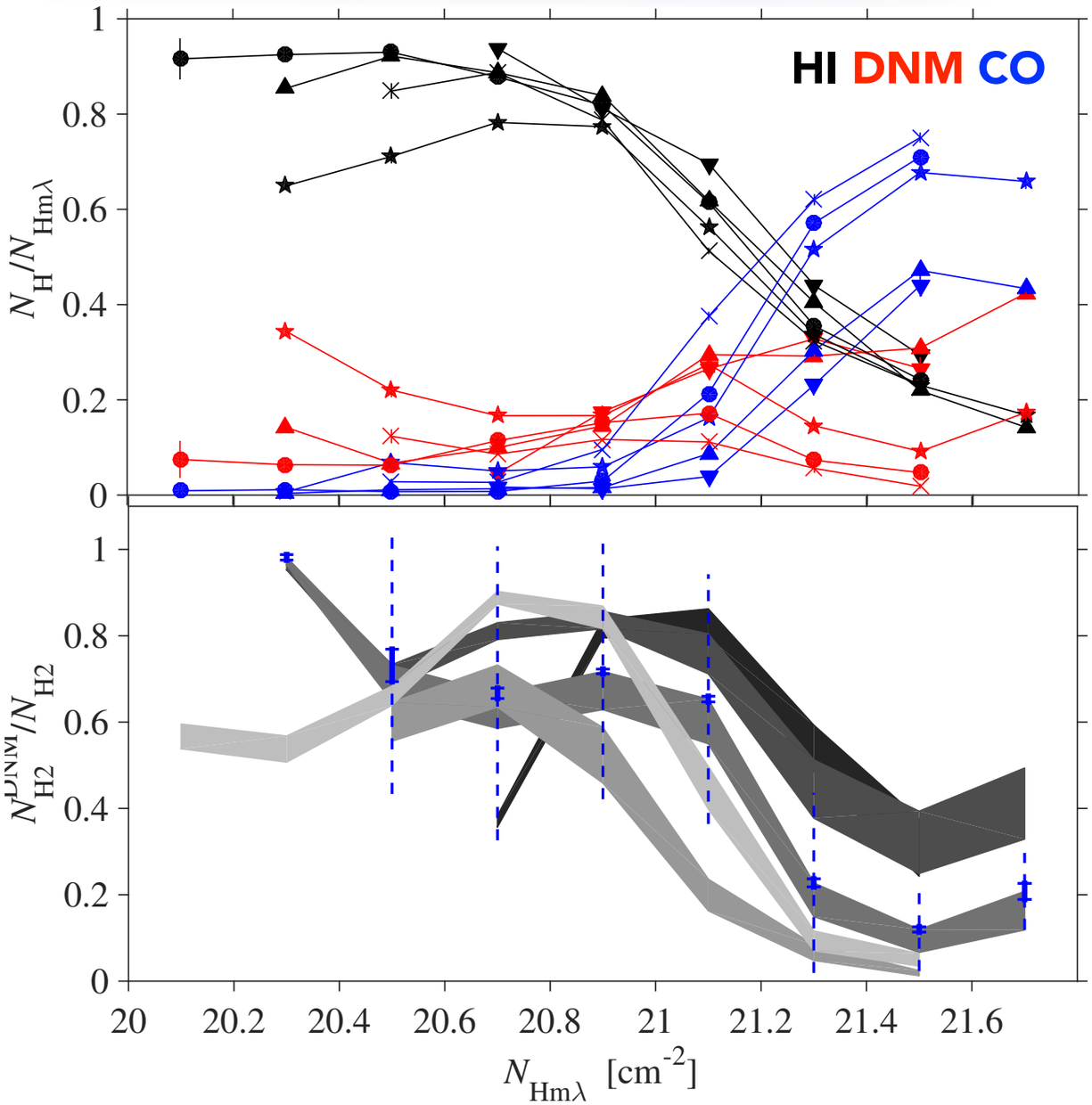


PRELIMINARY

phases transitions in the Chameleon complex

- HI decline around 8 10^{20} cm^{-2}
- CO onset around 1.5 10^{21} cm^{-2}
- HI-DNM transition
  - ✦ varies between clouds
  - ✦ retains 30% toward CO because of envelope





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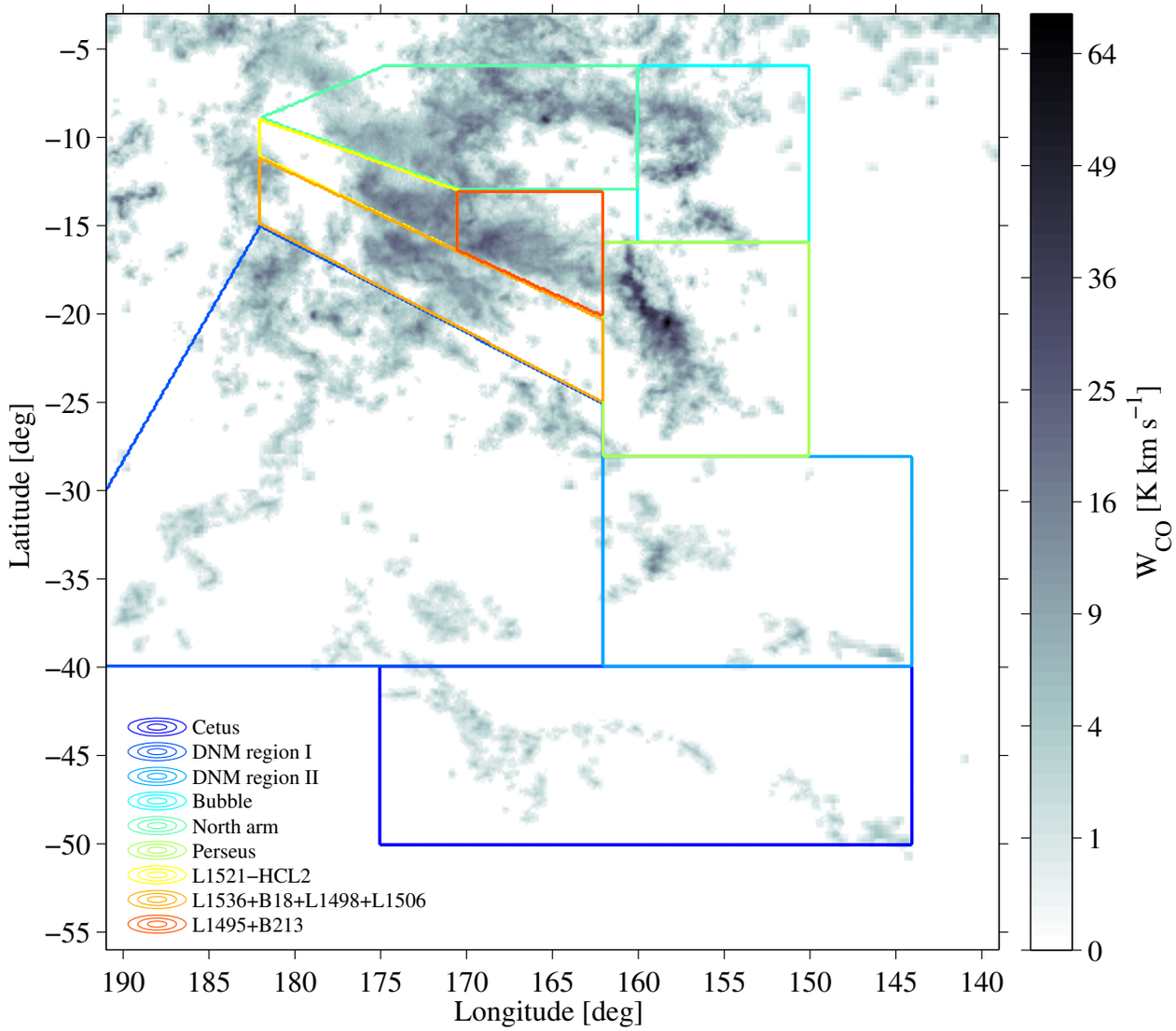
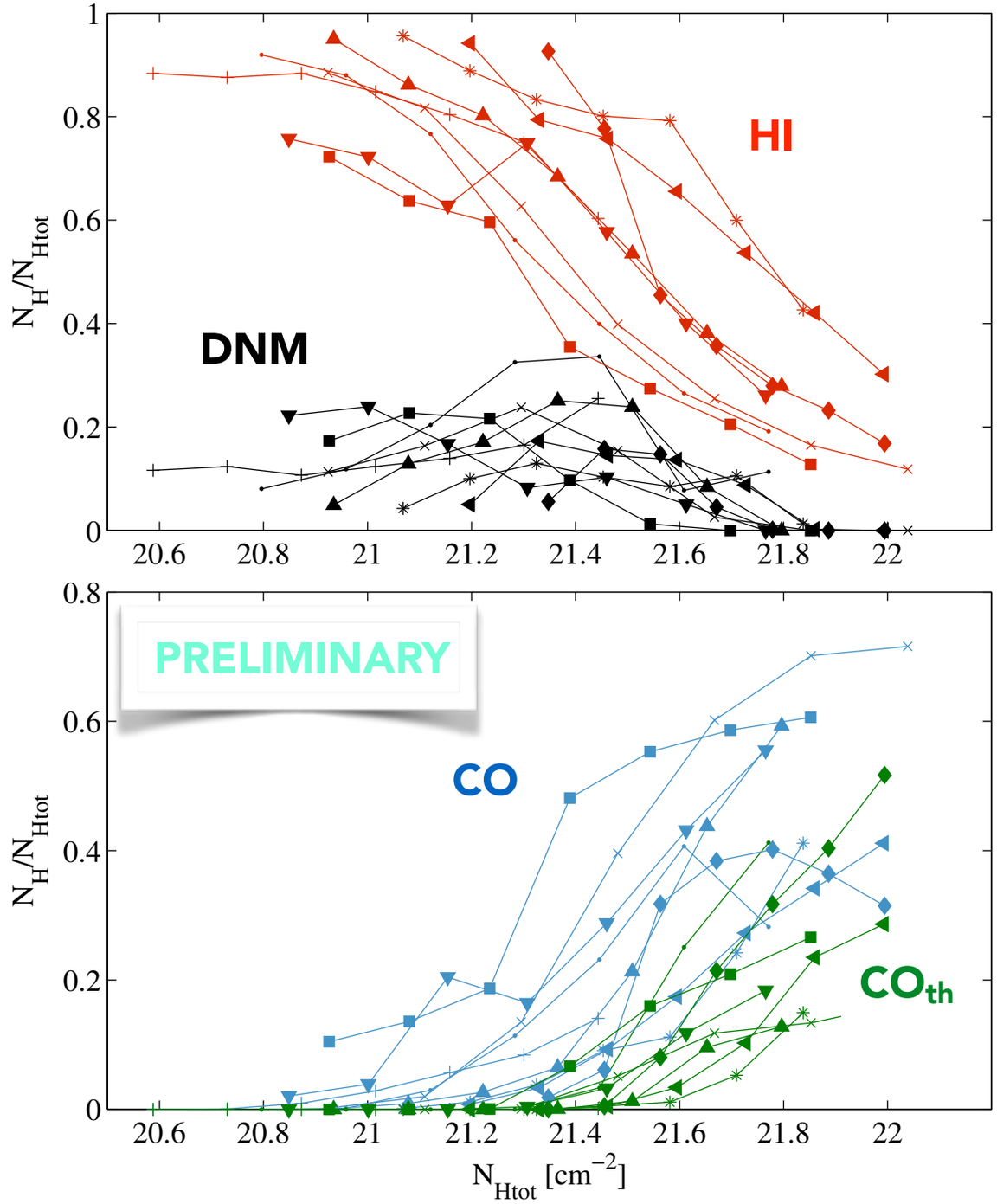
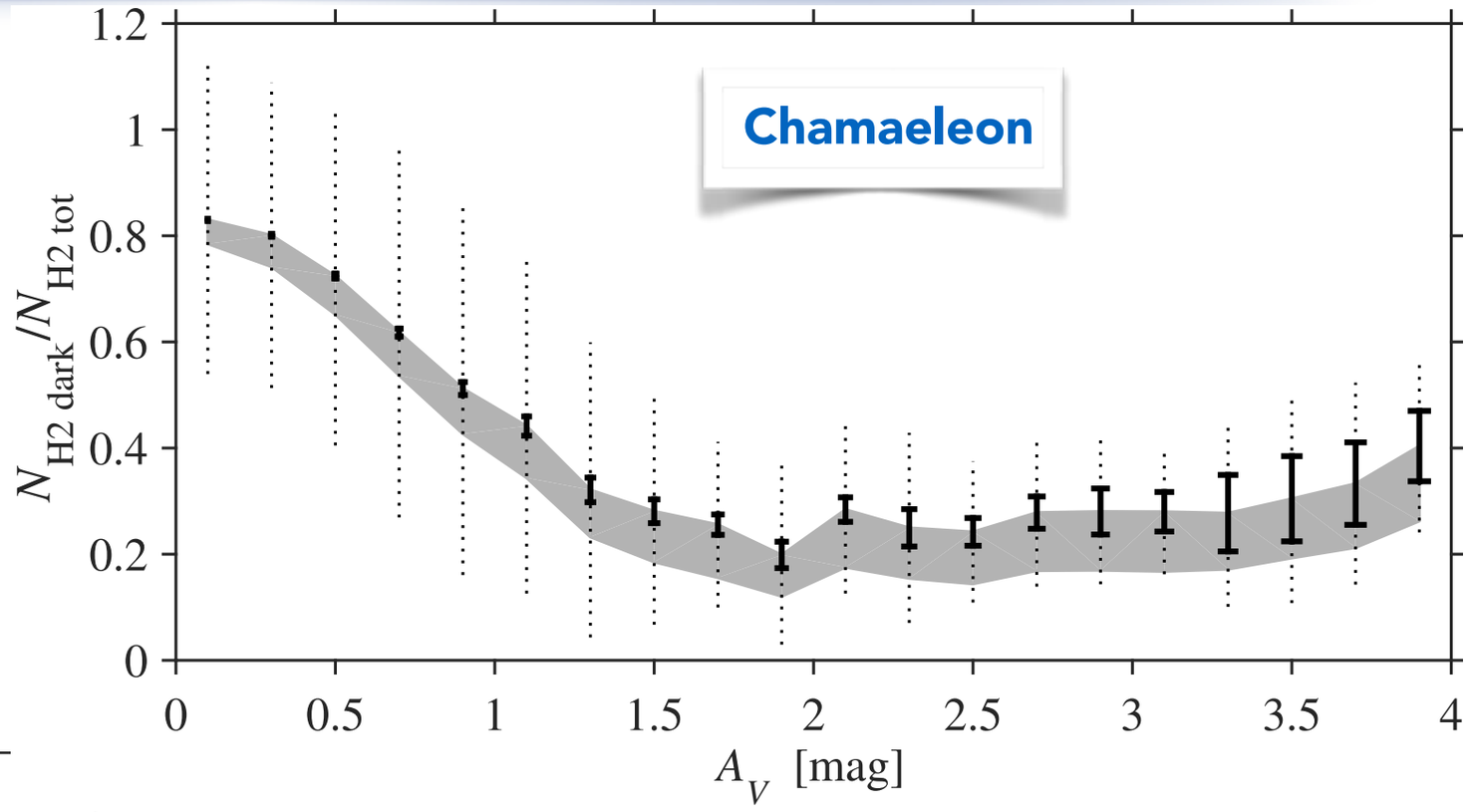
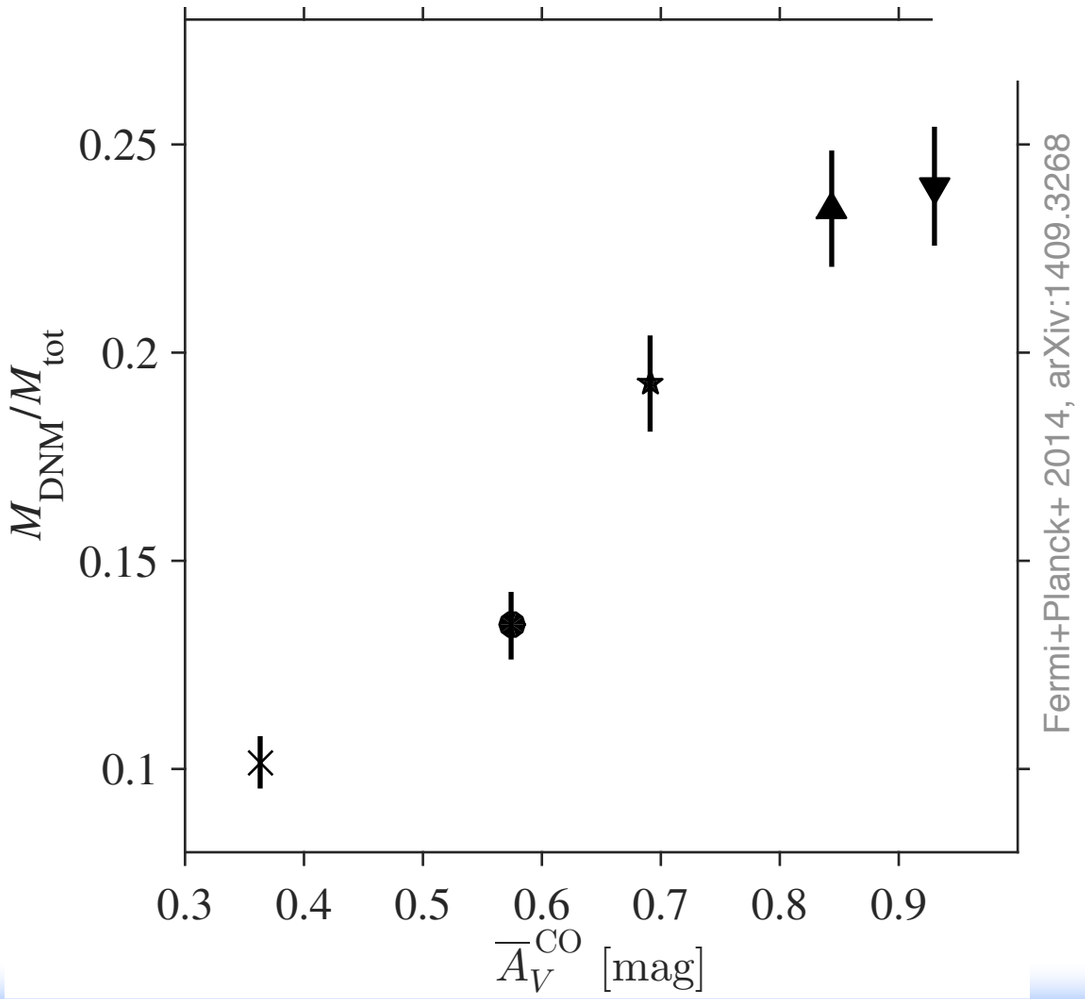


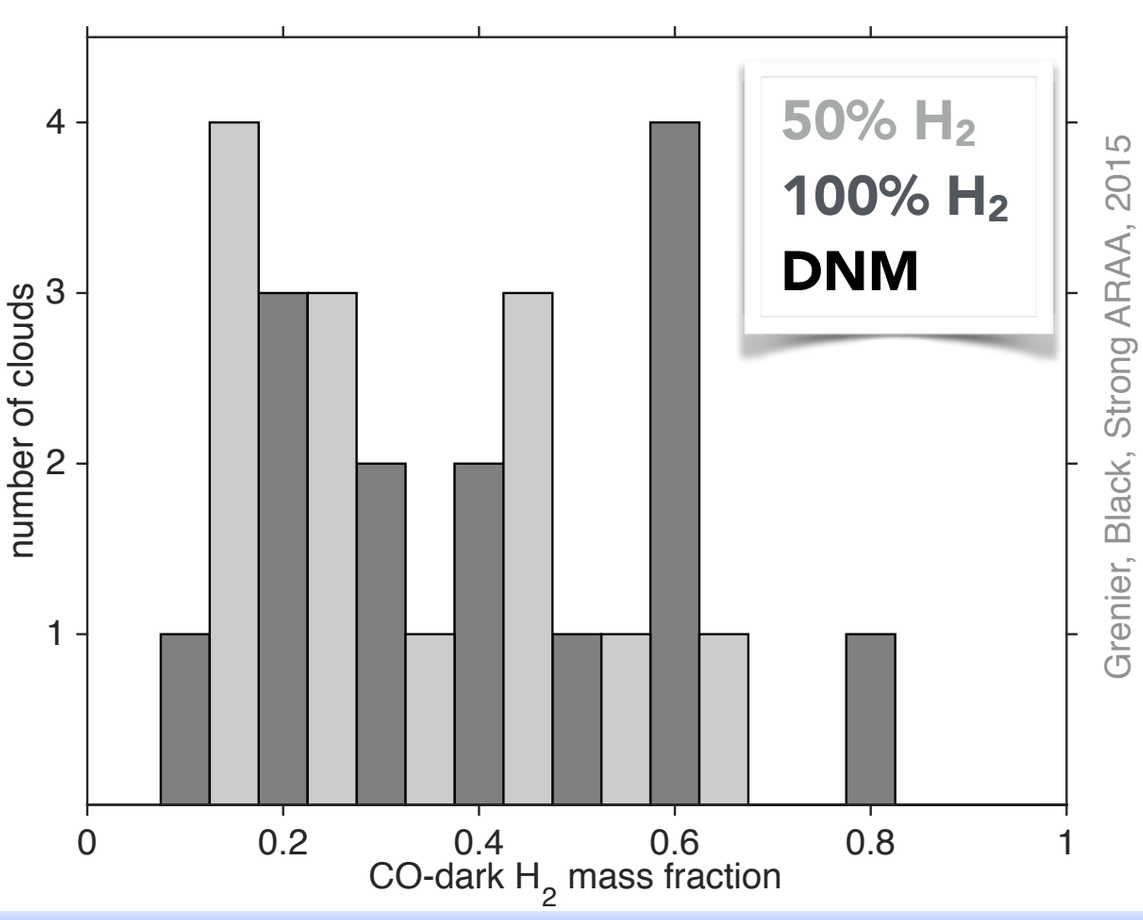


DNM-to-CO transition

- DNM dominates H_2 densities up to $A_V \approx 0.9$ mag in Cham
- DNM mass fractions:
  - ✦ wide range in local clouds
  - ✦ often exceeds the 30% theoretical expectation
  - ✦ unexplained rise with $\langle A_{VCO} \rangle$







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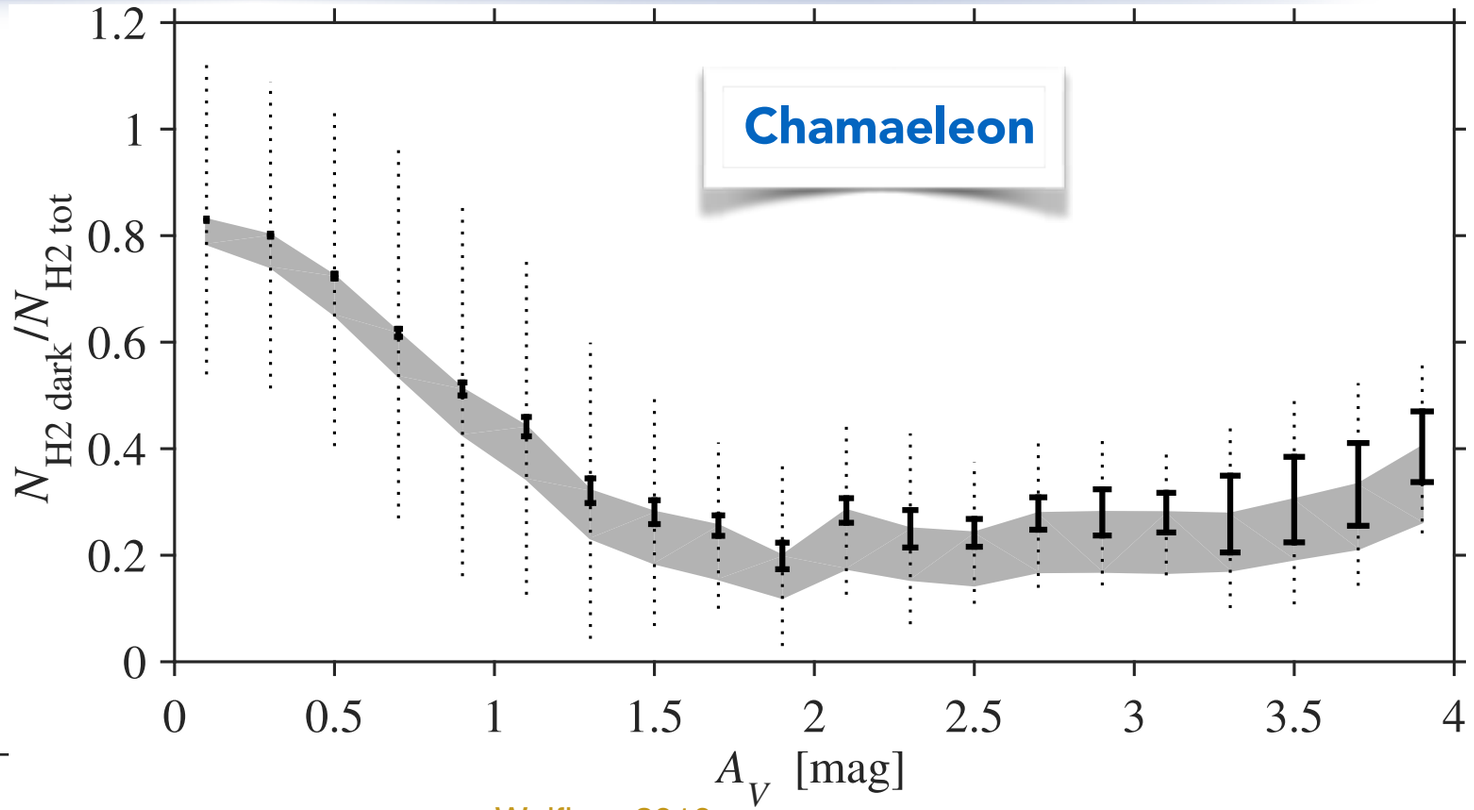

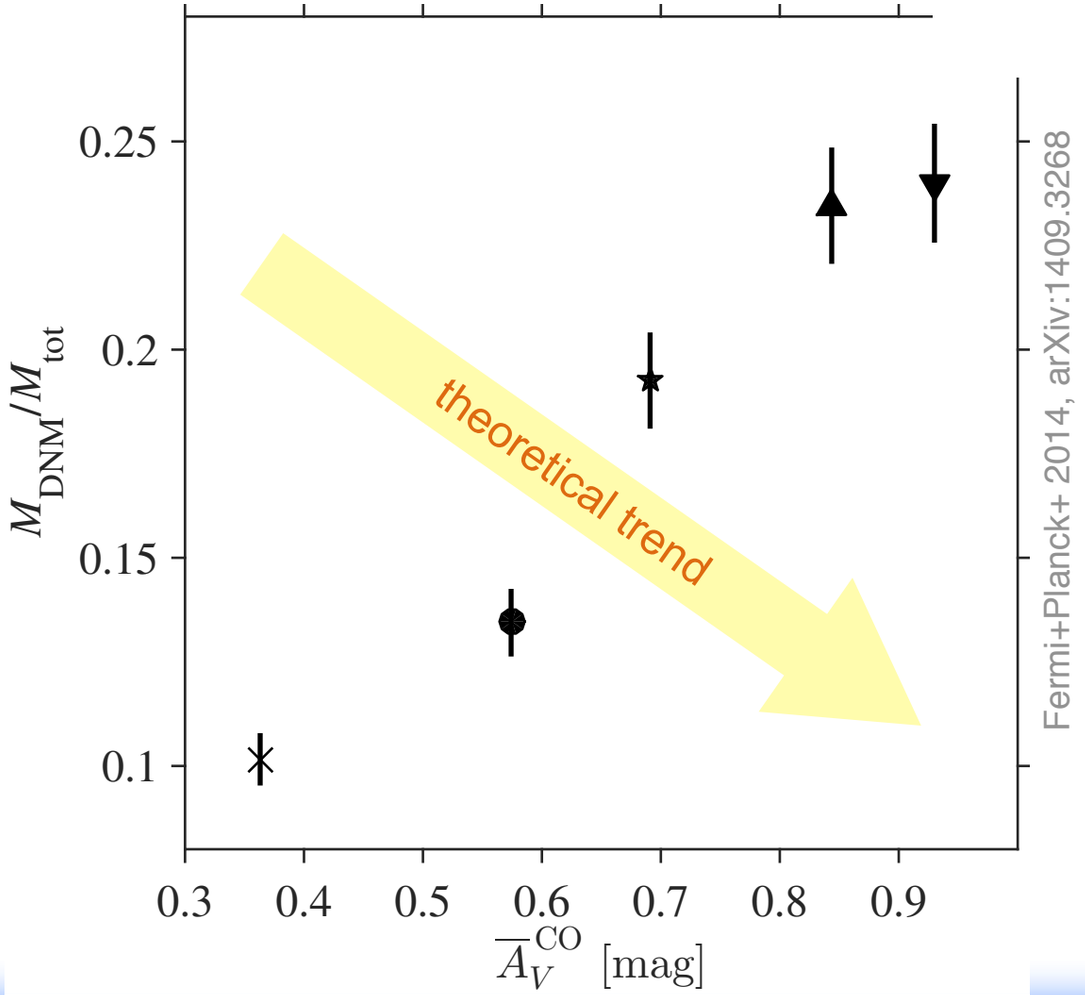

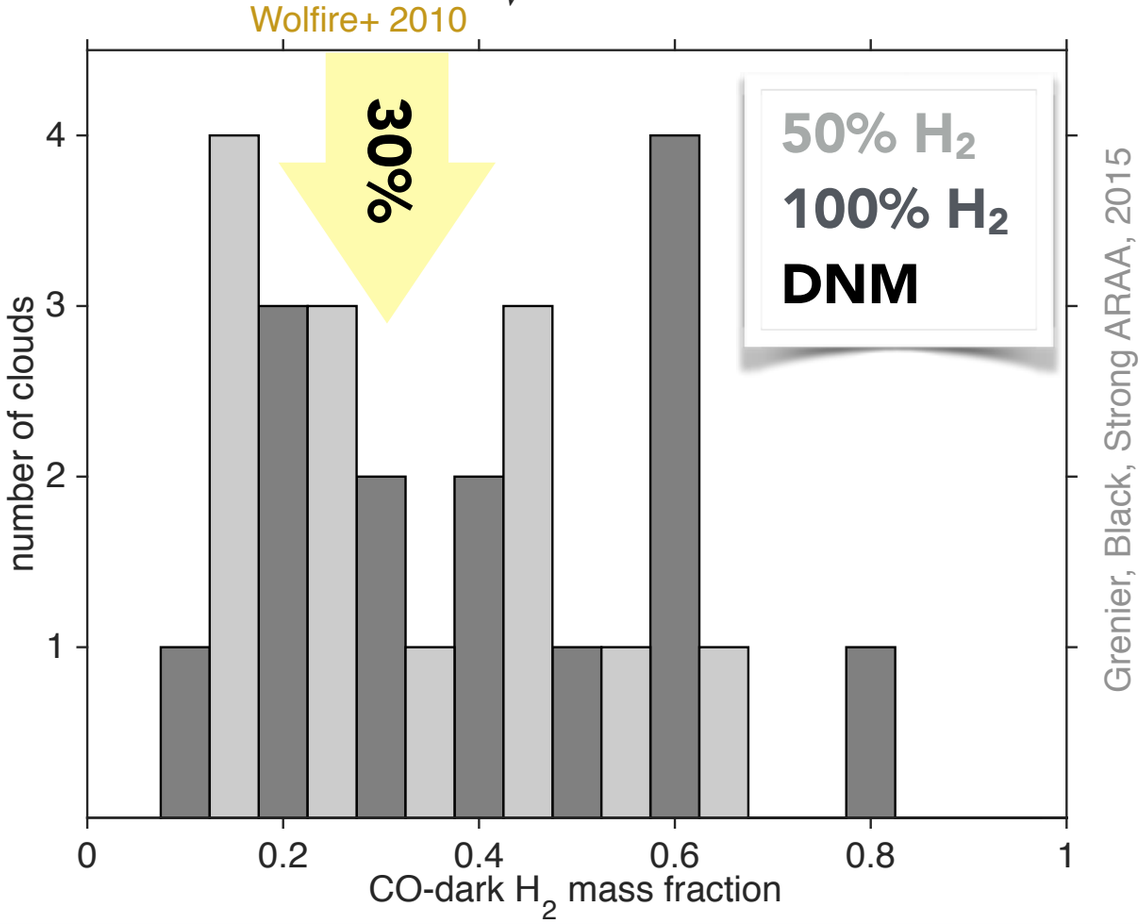

X_{CO} = CO-to-H_2 conversion ratio

- $X_{CO\gamma}$(kpc-scale) ≈ 2 $X_{CO\gamma}$(pc-scale) value
  - ✦ X_{CO}(pc) ≈ 0.9 10^{20} cm^{-2} $(K\ km/s)^{-1}$ X_{CO}(kpc) ≈ 1.9 10^{20} cm^{-2} $(K\ km/s)^{-1}$
  - ✦ possible causes: phase confusions ? pile-up along sightline?
  - ✦ $X_{CO\gamma}$ increase with radius: TBC ! $X_{12CO-13CO}$ increase due to assumed [Z]/[Z⊙] gradient !

- often $X_{CO dust}$ >> $X_{CO\gamma}$
  - ✦ due to dust evolution rather than cosmic-ray exclusion

- A_V/N_H ratios in the DNM
  - ✦ γ-ray estimates consistent with Bohlin+ 1978