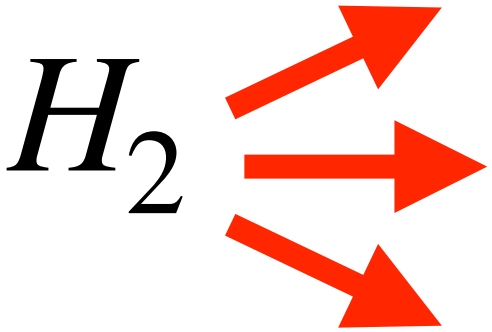
Molecular gas and dust extinction relation revealed by ALMaQUEST

Alice Concas

ESO fellow

Introduction
Observing Molecular Gas

Molecular Gas is the fuel of SF, key ingredient to understand SF & quenching in galaxies



- CO transitions
- Atomic Carbon [CI]
- Ionised Carbon [CII]
- Dust emission

Introduction
Observing Molecular Gas

Molecular Gas is the fuel of SF, key ingredient to understand SF & quenching in galaxies

H_2

- CO transitions
- Atomic Carbon [CI]
- Ionised Carbon [CII]
- Dust emission

\+ Dust absorption From Hα/Hβ

See also Concas&Popesso19; Brinchmann+2013; Boquien+2013; Kreckel+2013; BB+2018,2020

Introduction
Cold gas-Dust reddening relation in our Galaxy

A SURVEY OF INTERSTELLAR H I FROM Lα ABSORPTION MEASUREMENTS. II.

R. C. BOHLIN,*† B. D. SAVAGE,*‡ AND J. F. DRAKE§

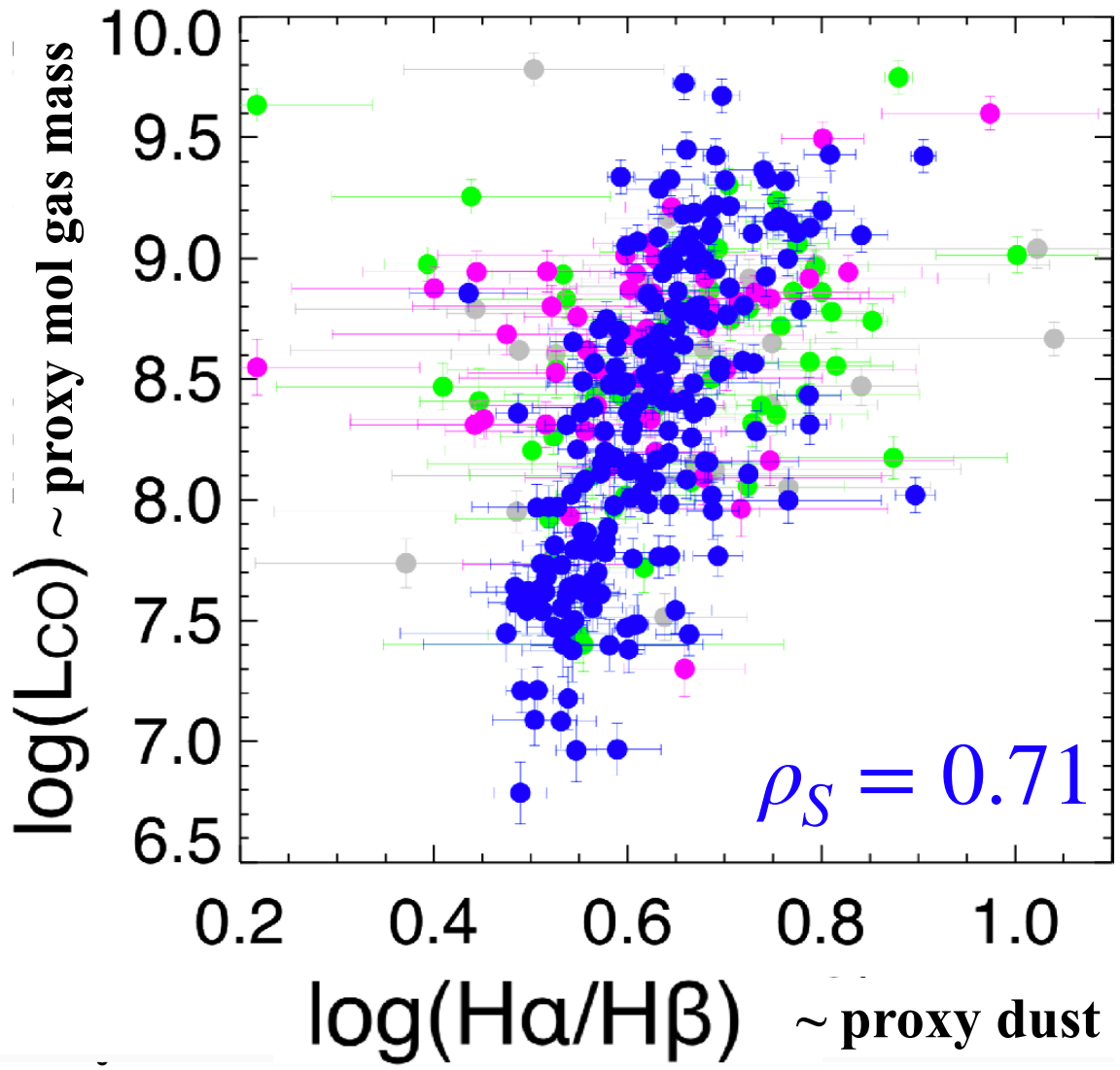
Received 1977 October 17; accepted 1978 February 23

ABSTRACT

The *Copernicus* satellite has surveyed the spectral region near Lα to obtain column densities of interstellar H I toward 100 stars. The distance to 10 stars exceeds 2 kpc and 34 stars lie beyond 1 kpc. Stars with color excess $E(B-V)$ up to 0.5 mag are observed. A definitive value is found for the mean ratio of total neutral hydrogen to color excess,

$$\langle N(\mathrm{H\,I} + \mathrm{H_2})/E(B-V)\rangle = 5.8 \times 10^{21} \text{ atoms cm}^{-2} \text{ mag}^{-1}.$$

Cold gas-Dust reddening relation on global scale in local SF galaxies



512 SDSS-selected galaxies

xCOLD GASS (Saintonge+2017)

@low z, $M_\star > 10^9 M_\odot$

- Global Molecular gas mass from L_{CO} (Noema)

+

- Dust extinction from optical line ratio $H\alpha$, $H\beta$ (SDSS spectroscopy)

SF, **AGNs**, **Composite**, **unClass**

Concas & Popesso 2019,

See also Popesso, Concas et al. 2020

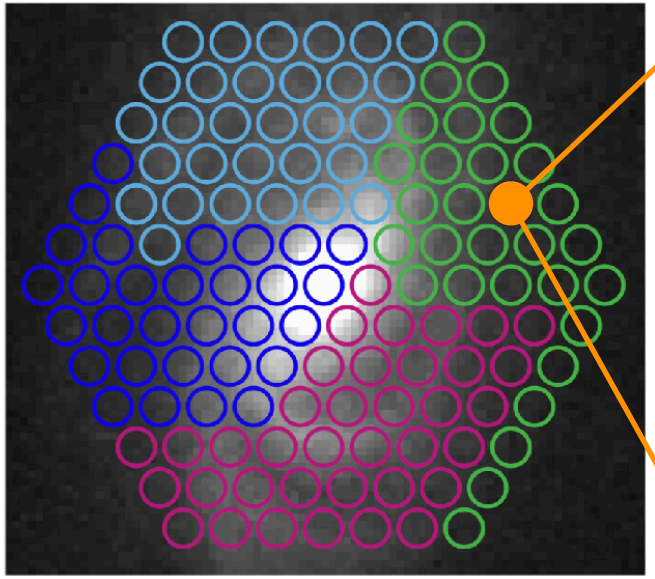
Cold gas-Dust reddening relation Kpc scale

ALMaQUEST

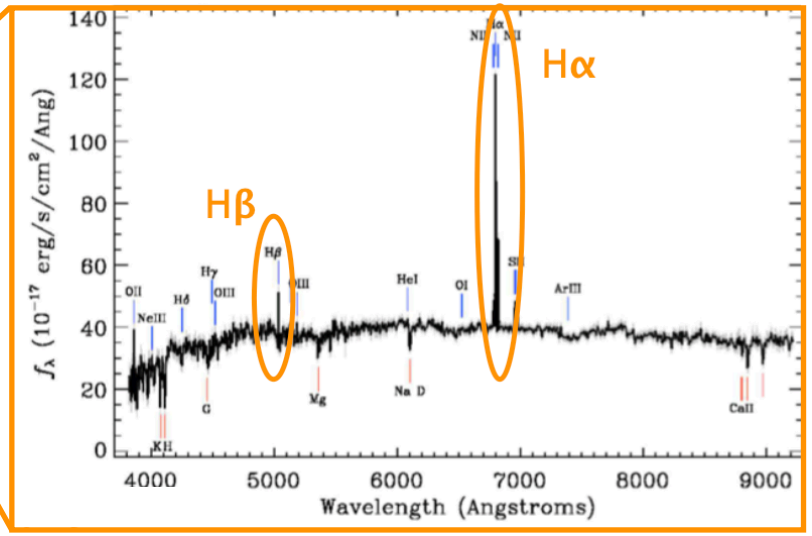
ALMA-MaNGA QUEnching and STar formation survey

PIs:Lin,Ellison

~47 local galaxies from MaNGA + 4 ALMA programs 12CO(1-0) at 2.5”



Optical IFU



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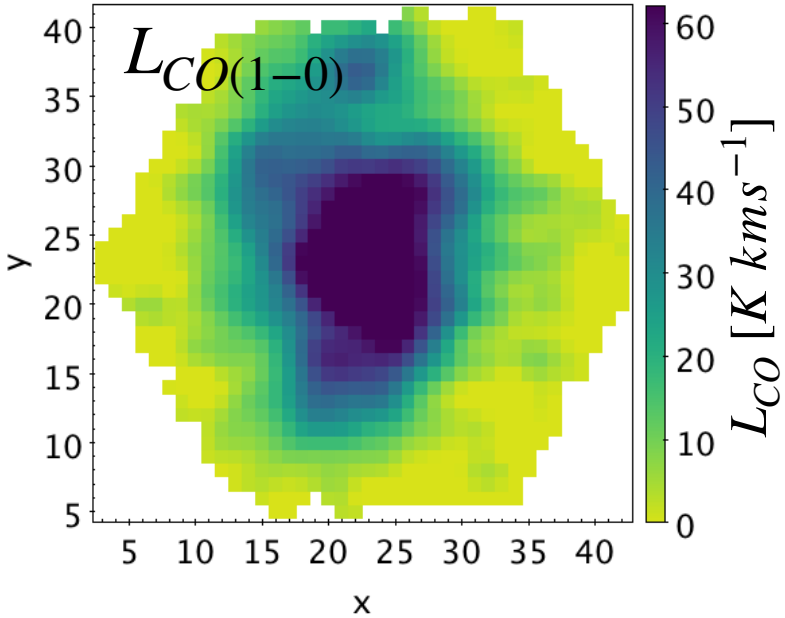
CO Intensity maps



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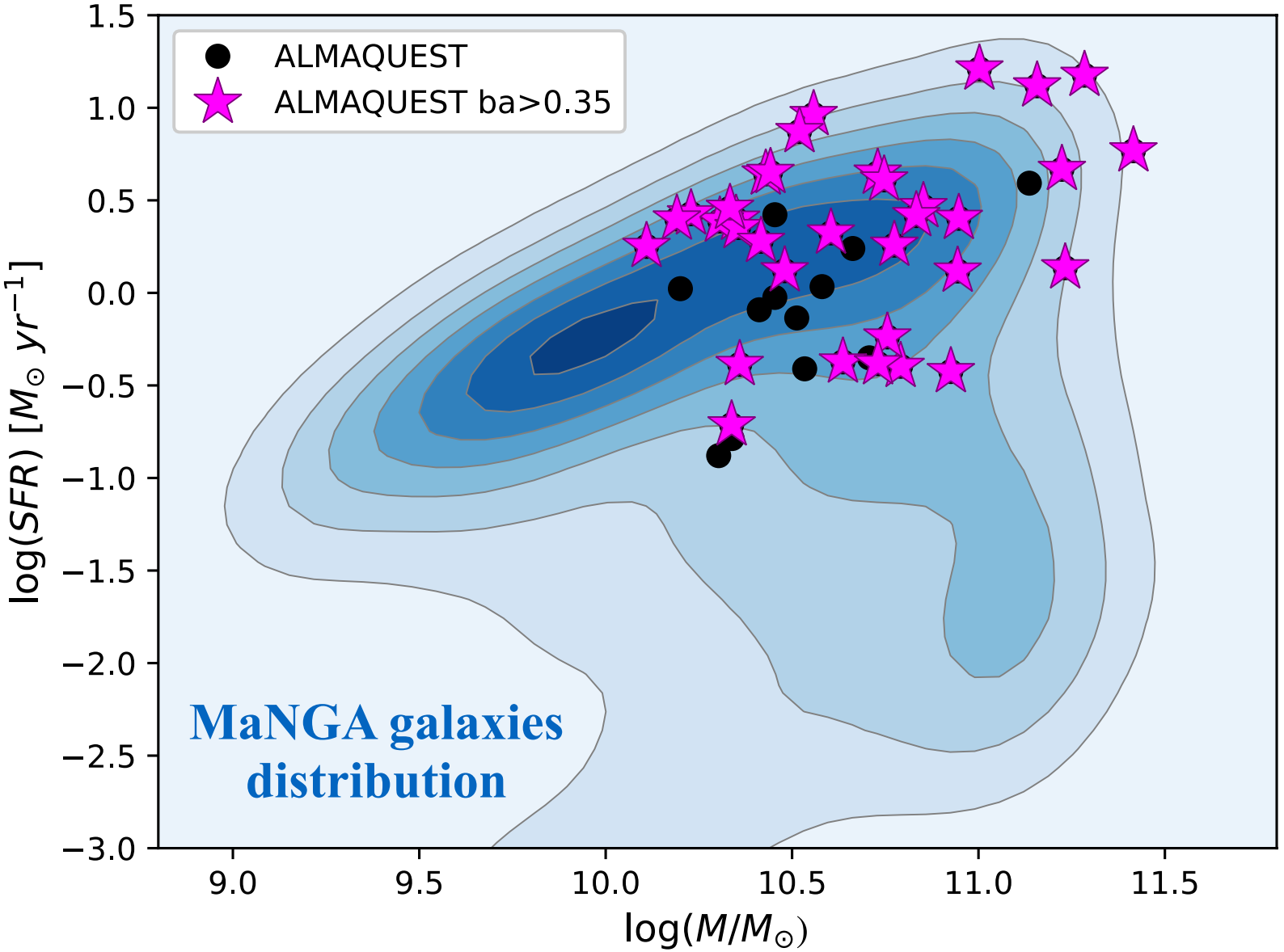
ALMaQUEST sample in the SFR-Mstar plane



★ 47 galaxies $M_\star > 10^{10} M_\odot$
On, above and below Main Sequence

★ Optical properties: $H\alpha, H\beta, [OIII], [NII]$ fluxes, $\Sigma_\star$, Σ_{SFR} from PIPE3D (Sanchez et al. 2016)

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ALMaQUEST Sample selection:

★ Only Star-Forming spaxels using BPT (Kauffmann et al. 2003)

★ SNR>3 for CO, $H\alpha$ & $H\beta$ emission lines

★ Inclination effects, i < 70deg, ba>0.34 (34 galaxies)

= 11561 spaxels

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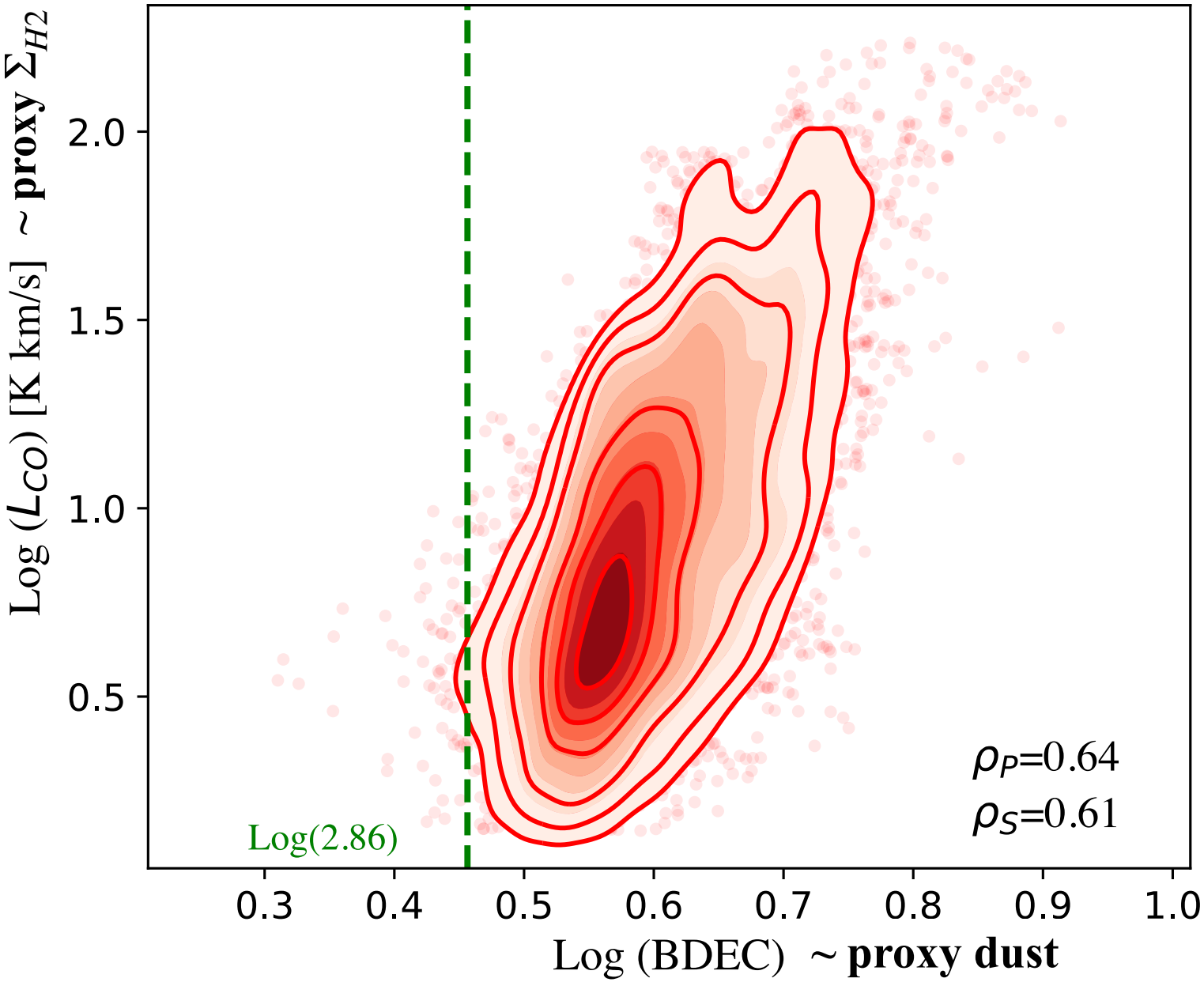
L_{CO} VS Balmer Decrement on kpc scale

ALMaQUEST



$$BDEC = \frac{F_{H\alpha}}{F_{H\beta}}$$

Moderate correlation:

Pearson $\rho = 0.64$

Spearman $\rho = 0.61$

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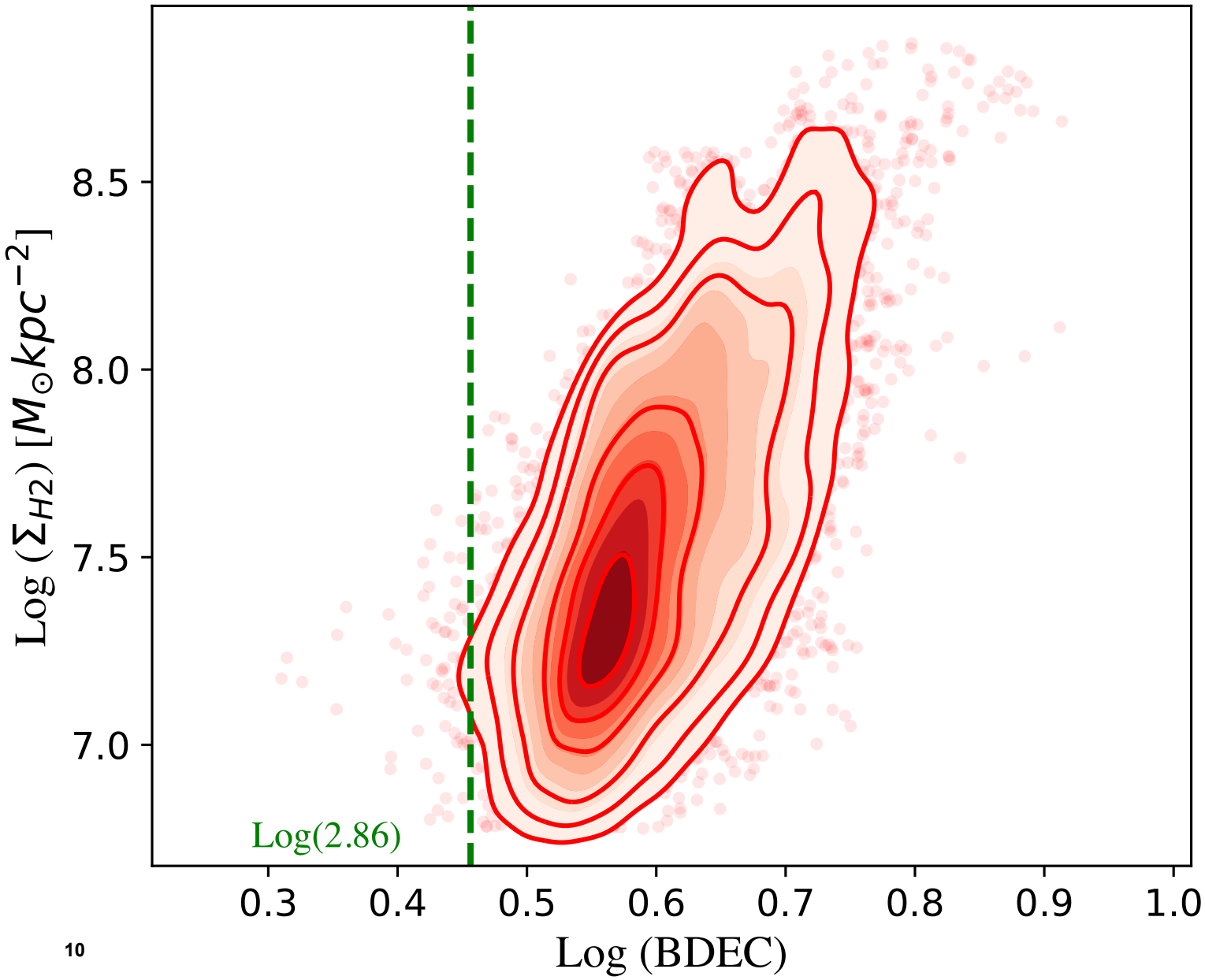
Σ_{H2} VS Balmer Decrement on kpc scale

ALMaQUEST



Assuming a constant conversion factor

$$\alpha_{CO} = 4.3 M_\odot pc^{-2} (K\ km\ s^{-1})$$

(e.g., Bolatto et al. 2013)

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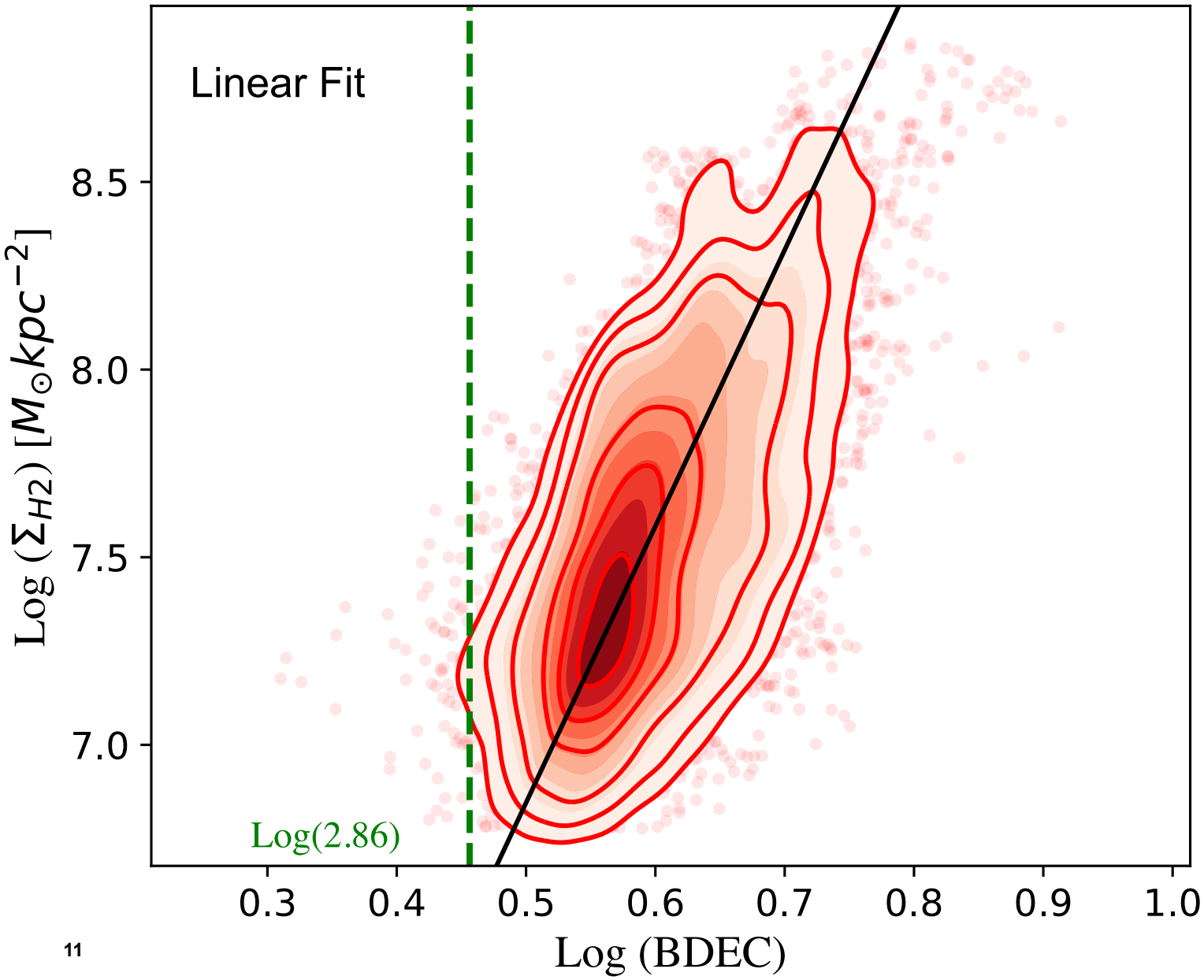

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Are we able to predict L_{CO}, Σ_{H2} from BDEC?

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Are we able to predict L_{CO}, Σ_{H2} from BDEC?

—> Test our empirical relation with CARMA EDGE-CALIFA survey

Spatially resolved $H\alpha/H\beta$ and CO emission

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Test with CARMA EDGE-CALIFA survey

(See Bolatto+2017)

~126 local galaxies observed with CARMA interferometer 12CO(1-0) and CALIFA optical IFU

Same sample selection:

★ Only Star-Forming spaxels using BPT (Kauffmann et al. 2003)

★ SNR>10 $H\alpha$ & $H\beta$, CO mom0/mom0_sig>1

★ Inclination effects, i < 70deg, ba>0.34

= 3730 spaxels

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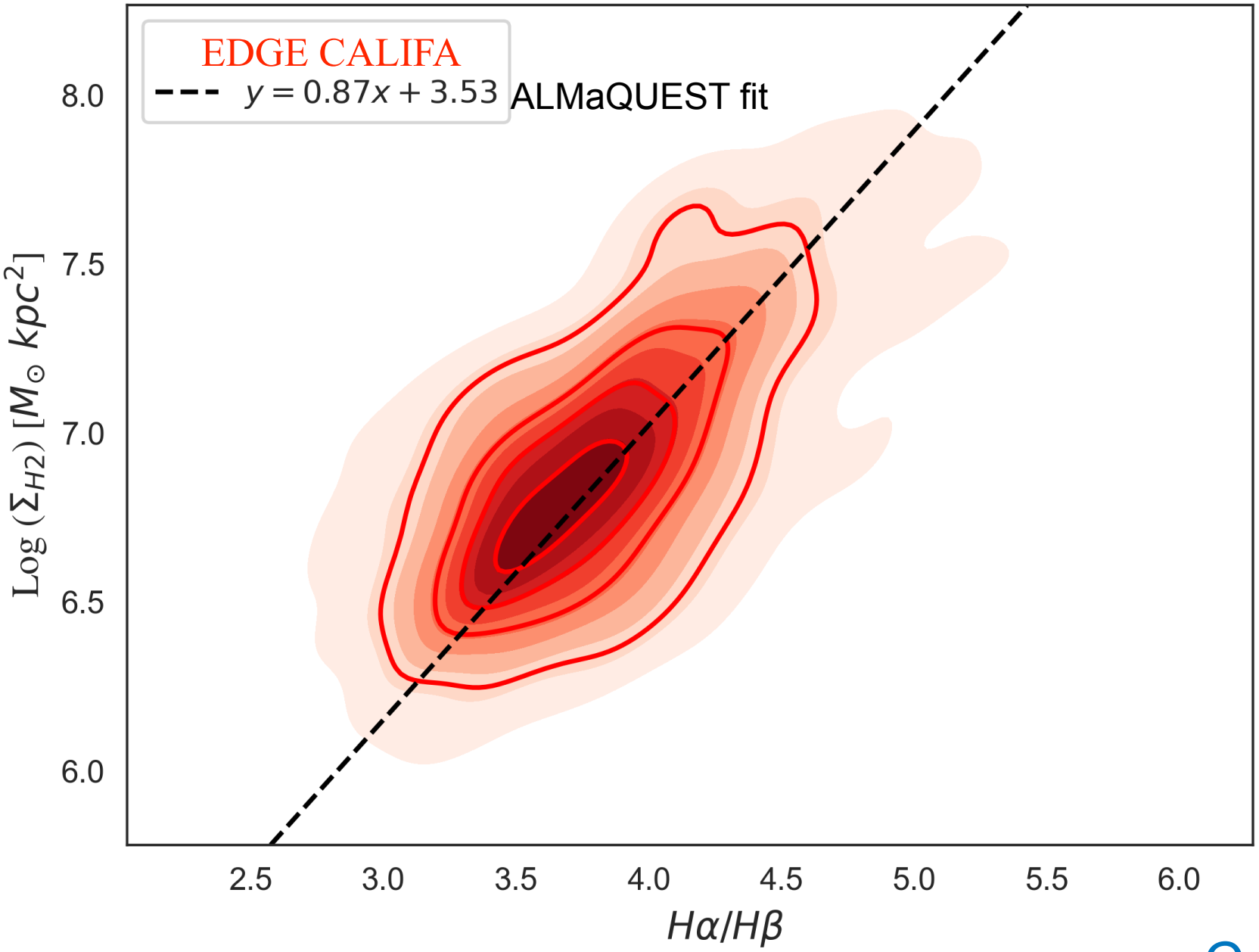
Spaxels at approximately the Nyquist rate, i.e. only 1 spaxel in every 3 is included.

EDGE-CALIFA distribution VS ALMAQUEST best fit line



Face-on
ba>=0.6

2240
EDGE-CALIFA
spaxels

Concas+ in prep.

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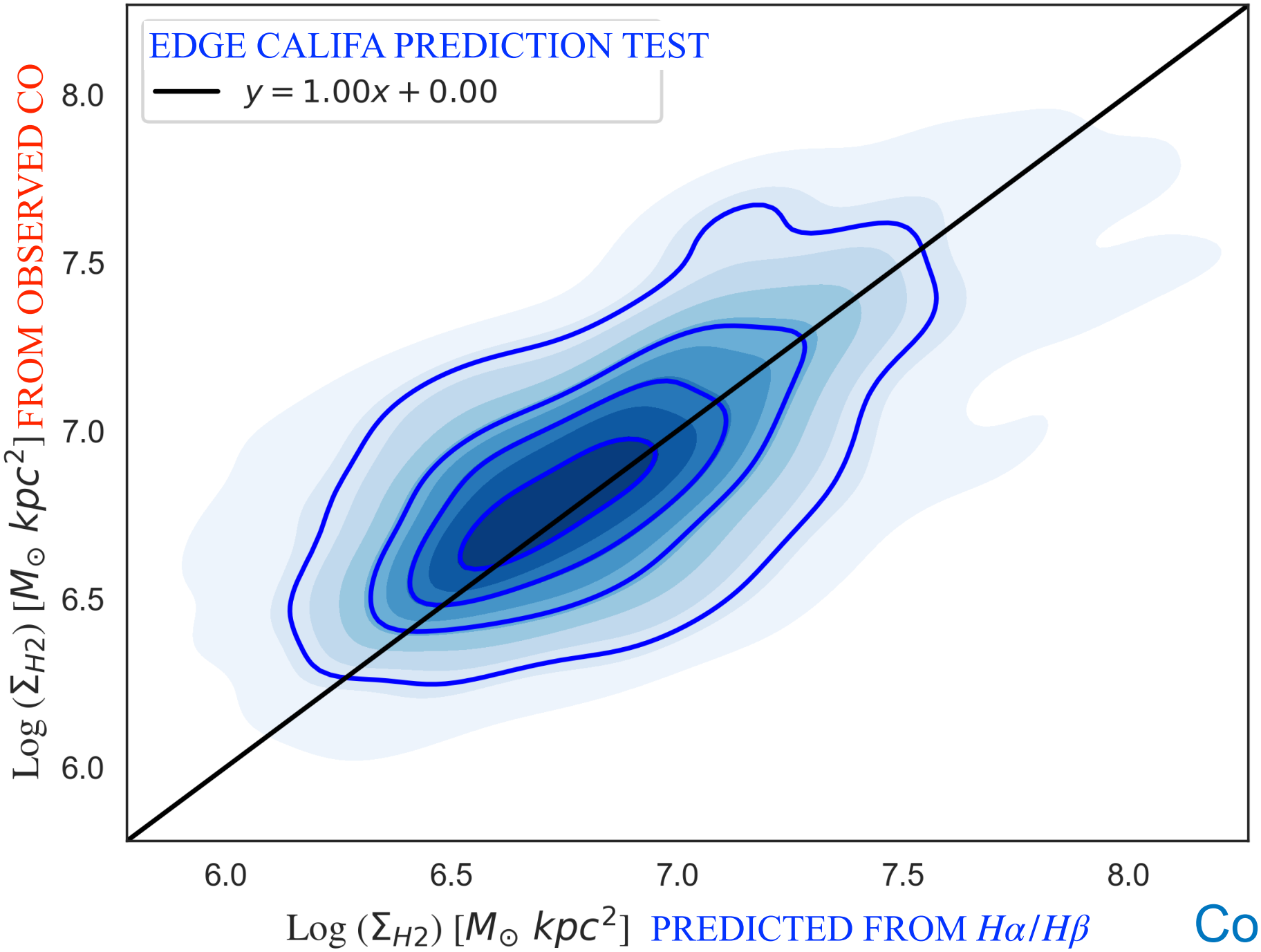

Face-on
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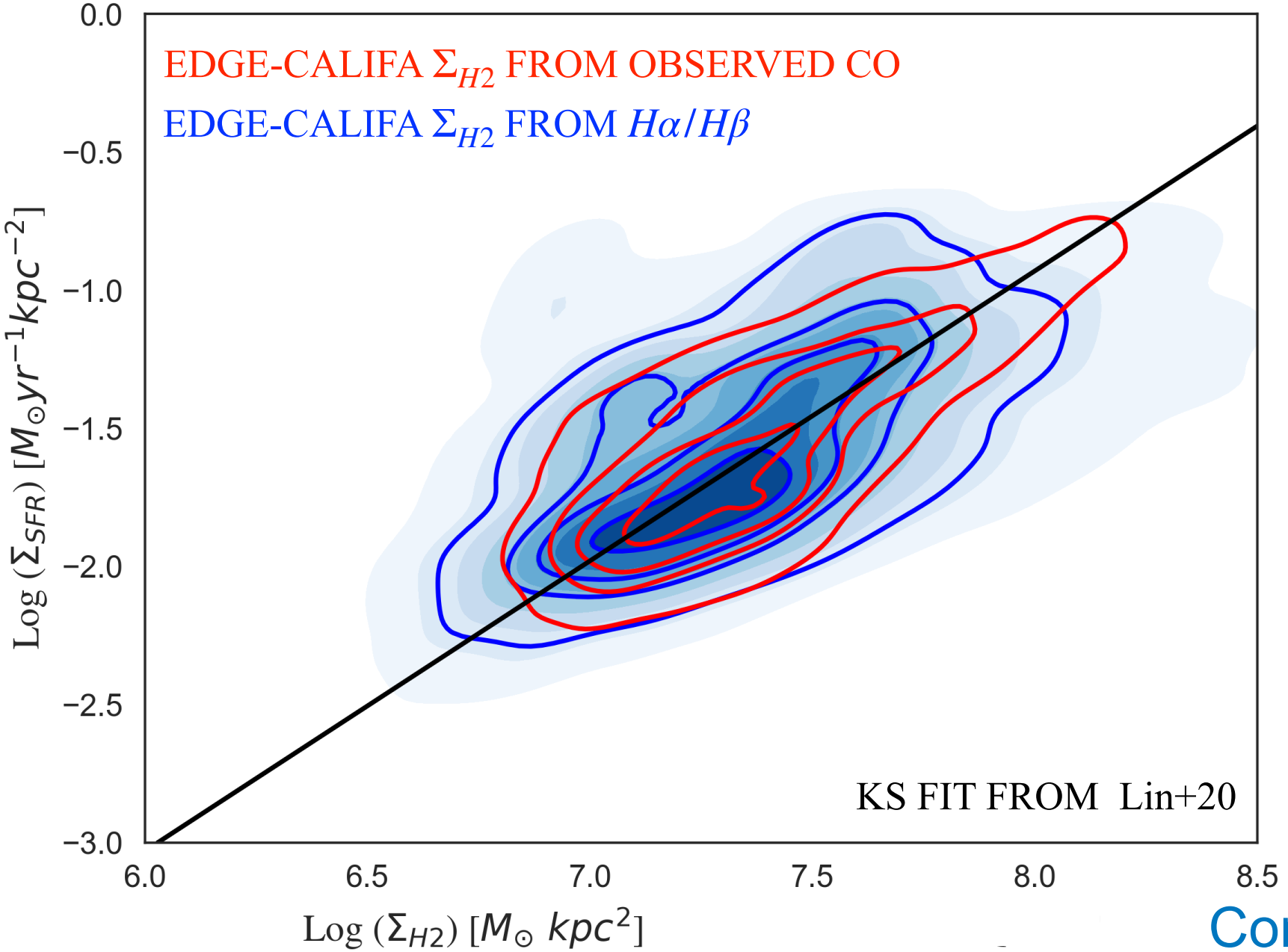
Kennicutt-Schmidt Relation with predicted Σ_{H2} from $H\alpha/H\beta$ lines



Face-on
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2240
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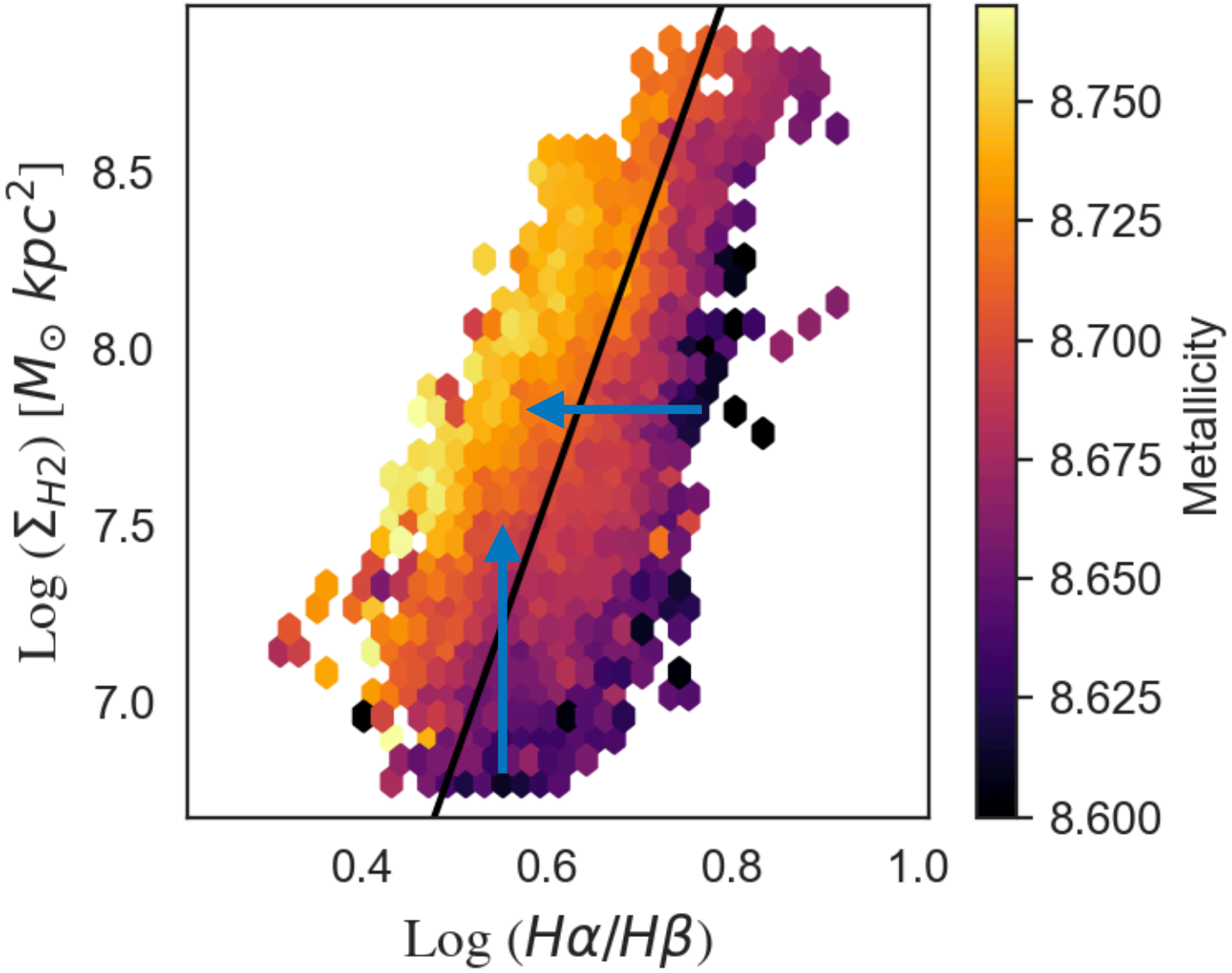
Σ_{H2} - BDec relation and metallicity variation

ALMaQUEST



At fixed Σ_{H2}

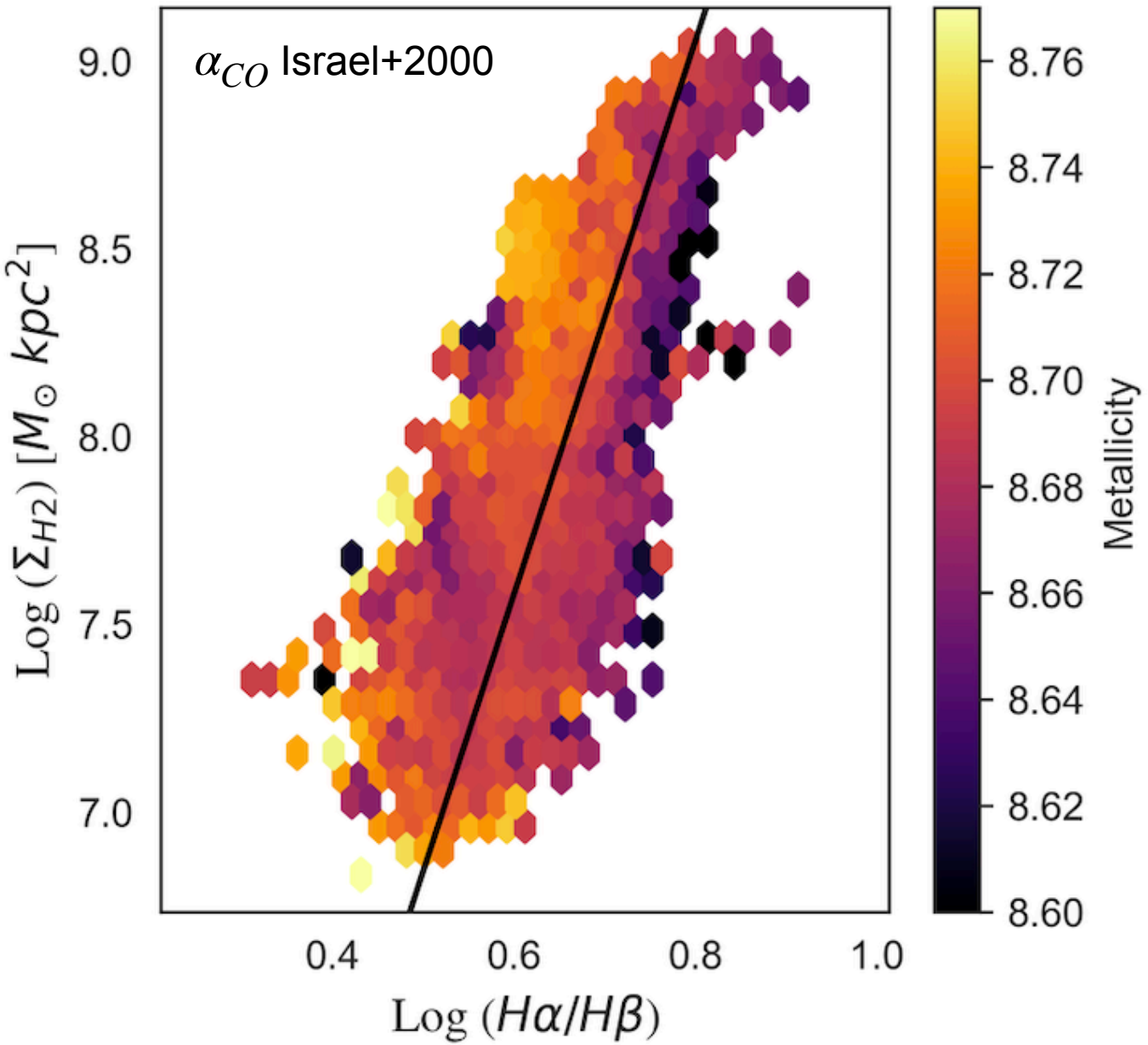
the metallicity decreases with BDec

At fixed Bdec

the metallicity increases with Σ_{H2}

Concas+ in prep.

Σ_{H2} - BDec relation and metallicity variation



At fixed Σ_{H2}

the metallicity increases with BDec

At fixed Bdec

the metallicity increases with Σ_{H2}

The effect disappears if we assume a variable α_{CO} conversion factor!

Higher correlation factors

Pearson $\rho = 0.69$

Spearman $\rho = 0.63$

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Understand the metallicity variation in the Σ_{H2} - BDec relation

$$\Sigma_{gas} = \frac{1}{DGR}\Sigma_{dust}$$ **and** $$\Sigma_{dust} \approx \tau_V$$

dust optical depth

$$\tau_V = f(H\alpha/H\beta)$$

Concas+ in prep.

Understand the metallicity variation in the Σ_{H2} - BDec relation

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$$\Sigma_{gas} = \Sigma_{HI} + \Sigma_{H2} \qquad \text{If} \quad \Sigma_{HI} \sim 0$$

$$\longrightarrow \Sigma_{gas} \approx \Sigma_{H2}$$

dust optical depth

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$$\longrightarrow \Sigma_{gas} \approx \Sigma_{H2} \sim \alpha_{CO} I_{CO}$$

dust optical depth

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$$\longrightarrow \Sigma_{gas} \approx \Sigma_{H2} \sim \alpha_{CO} I_{CO} \sim \frac{1}{DGR}\tau_V$$

dust optical depth

$$\tau_V = f(H\alpha/H\beta)$$

$$\alpha_{CO} = f(Z) \qquad DGR = f(Z)$$

Metallicity!!!

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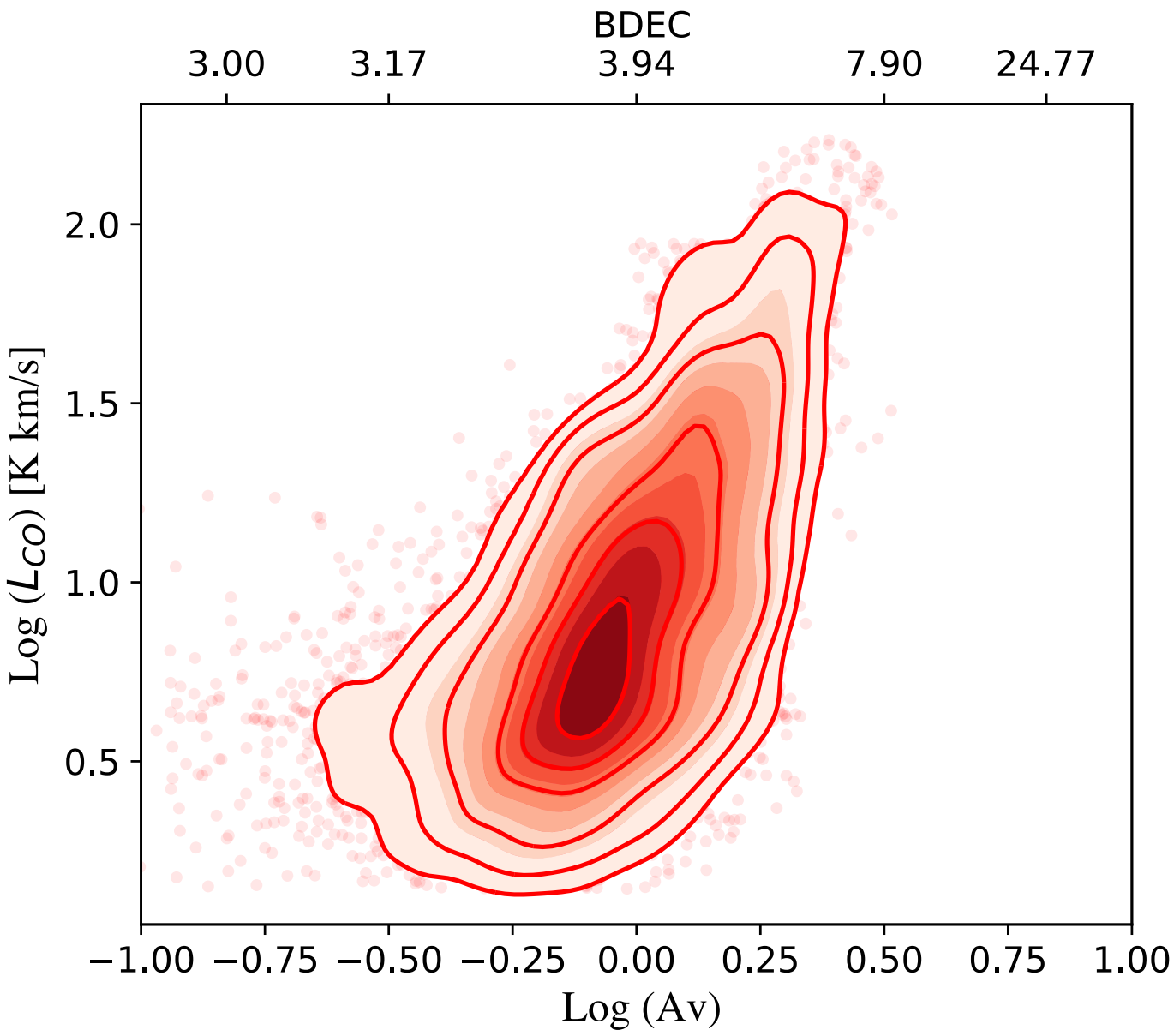
Comparison with previous results



Dust attenuation for the Hα line:

$$A_{H\alpha} = \frac{K_{H\alpha}}{-0.4\,(K_{H\alpha} - K_{H\beta})} \times \log\left(\frac{F_{H\alpha}/F_{H\beta}}{2.86}\right)$$

Optical extinction:

$$A_V = A_{H\alpha}/0.817$$

Assumptions:

extinction-free $H\alpha/H\beta$ flux ratio = 2.86
(Osterbrock 1989)
RV = 3.1
(Cardelli, Clayton & Mathis 1989, Cardelli+1989)

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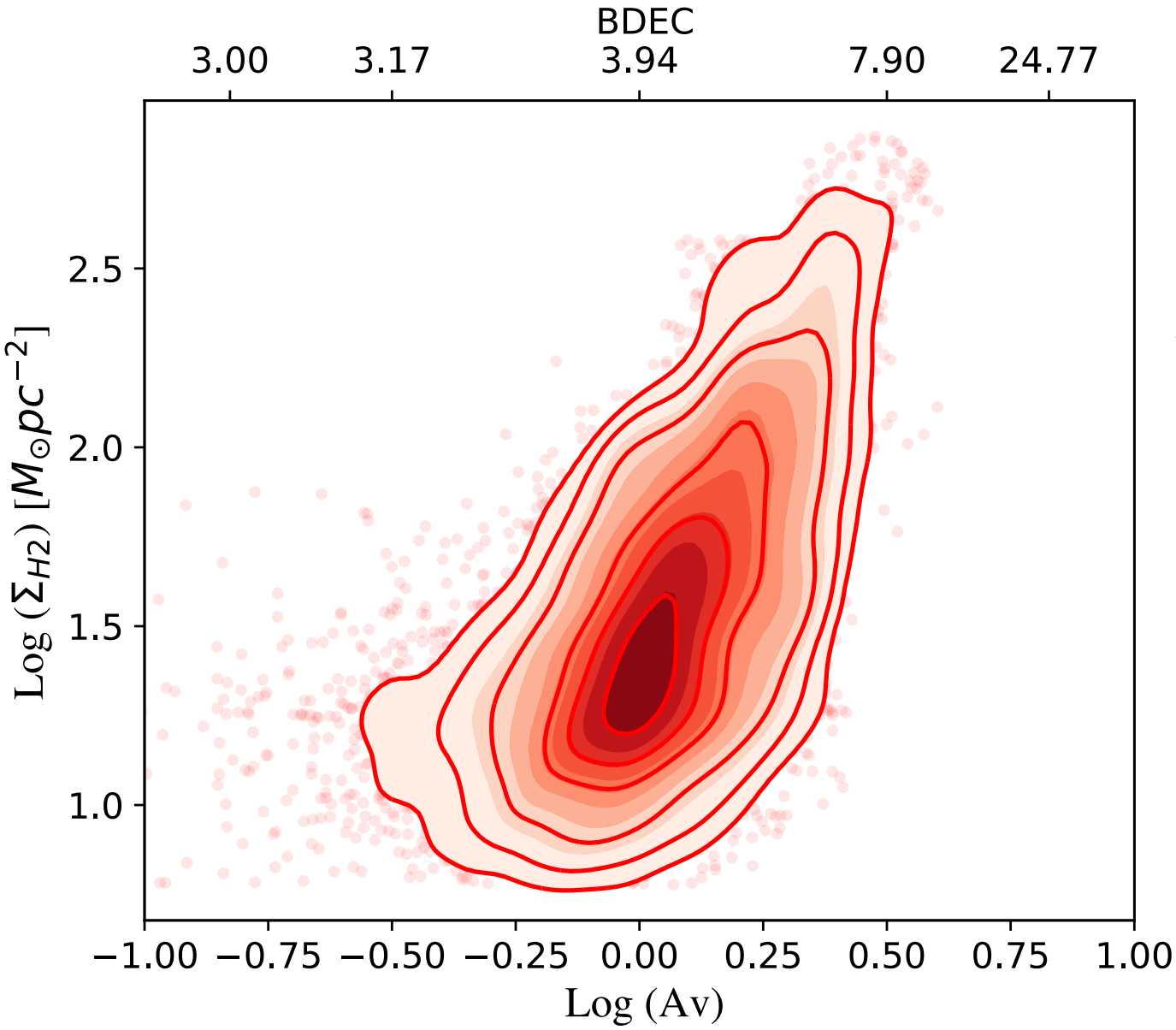
Comparison with previous results



Assuming a constant conversion factor

$$\alpha_{CO} = 4.3 M_\odot pc^{-2} (K\ km\ s^{-1})$$

(e.g., Bolatto et al. 2013).

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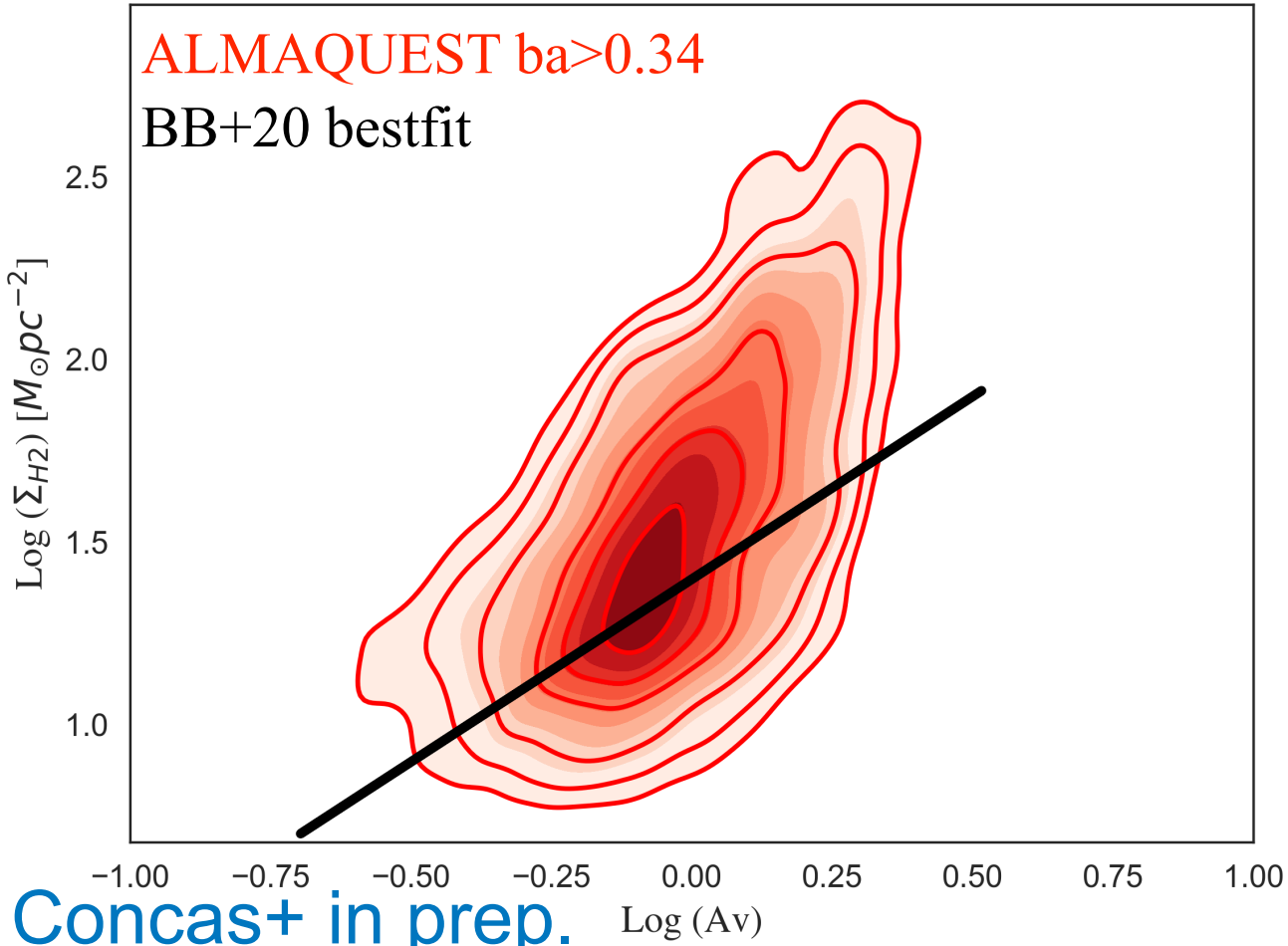
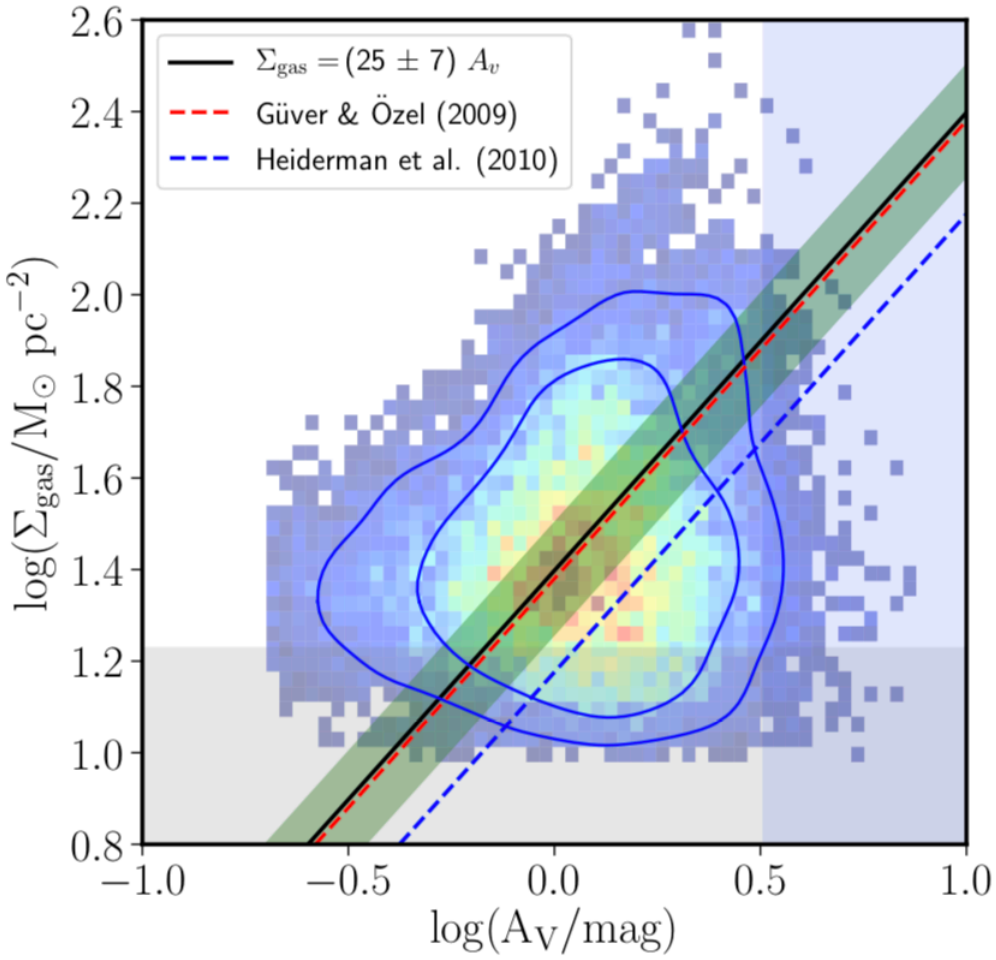
Comparison with previous results

Barrera-Ballesteros+20 data from EDGE-CALIFA survey

Larger scatter probably due to sample selection





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Understand the physics behind the Cold gas - Balmer Decrement relation

$$\Sigma_{gas} = \frac{1}{DGR}\Sigma_{dust} \quad \text{and} \quad \Sigma_{dust} \approx \tau_V \longrightarrow \Sigma_{gas} \approx \frac{1}{DGR}\tau_V$$

$$\Sigma_{gas} = \Sigma_{HI} + \Sigma_{H2} \qquad \text{If} \quad \Sigma_{HI} \sim 0$$

$$\longrightarrow \Sigma_{gas} \approx \Sigma_{H2} \sim \alpha_{CO} I_{CO} \sim \frac{1}{DGR}\tau_V$$

dust optical depth

$$\tau_V = f(H\alpha/H\beta)$$

The relation between τ_V and observed BDEC depends on the relative geometry of dust and emitters (e.g. Natta+Panagia 1984, Disney+1989, Calzetti+1994)

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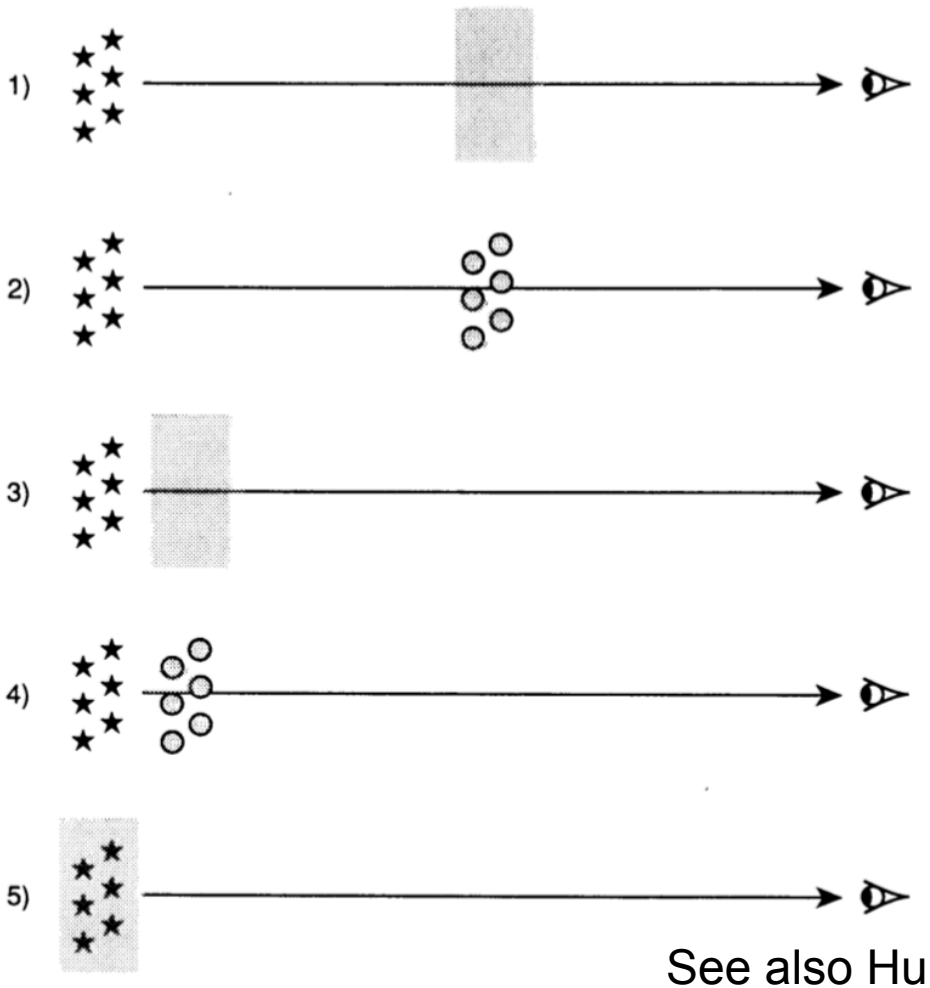
Understand the physics behind the Cold gas - Balmer Decrement relation

E.g. from Calzetti+1994



$$A_{H\alpha} = \frac{K_{H\alpha}}{-0.4\,(K_{H\alpha} - K_{H\beta})} \times \log\left(\frac{F_{H\alpha}/F_{H\beta}}{2.86}\right)$$

$$A_V = A_{H\alpha}/0.817$$

Simple case= foreground screen

$$\tau_V = A_V/1.086$$

More realistic case= dust uniformly mixed

$$\tau_V = W(-10^{0.4A_V} e^{-10^{0.4A_V}}) + 10^{0.4A_V}$$

W= Lambert W function

See also Hunt et al. 2023

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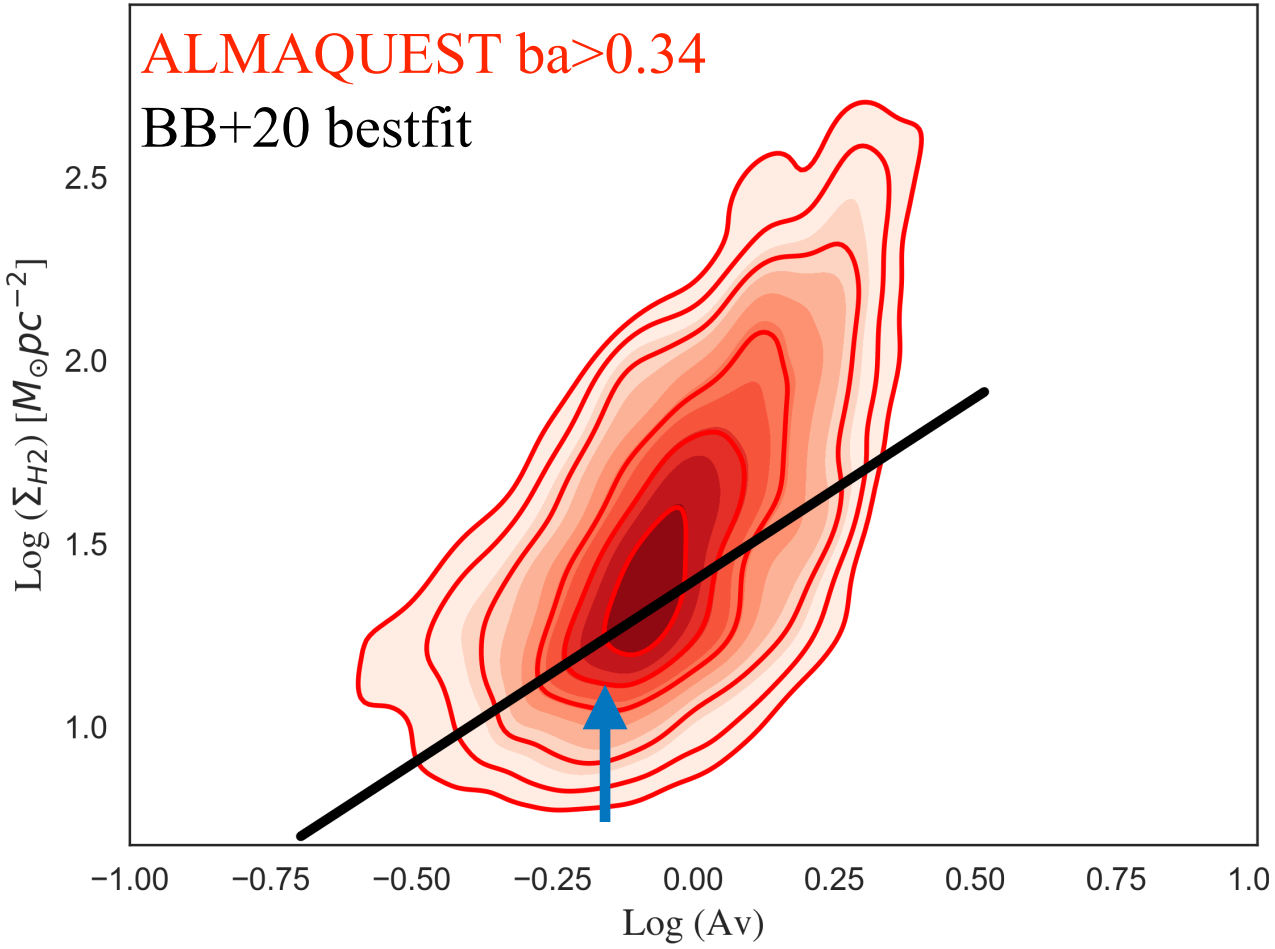
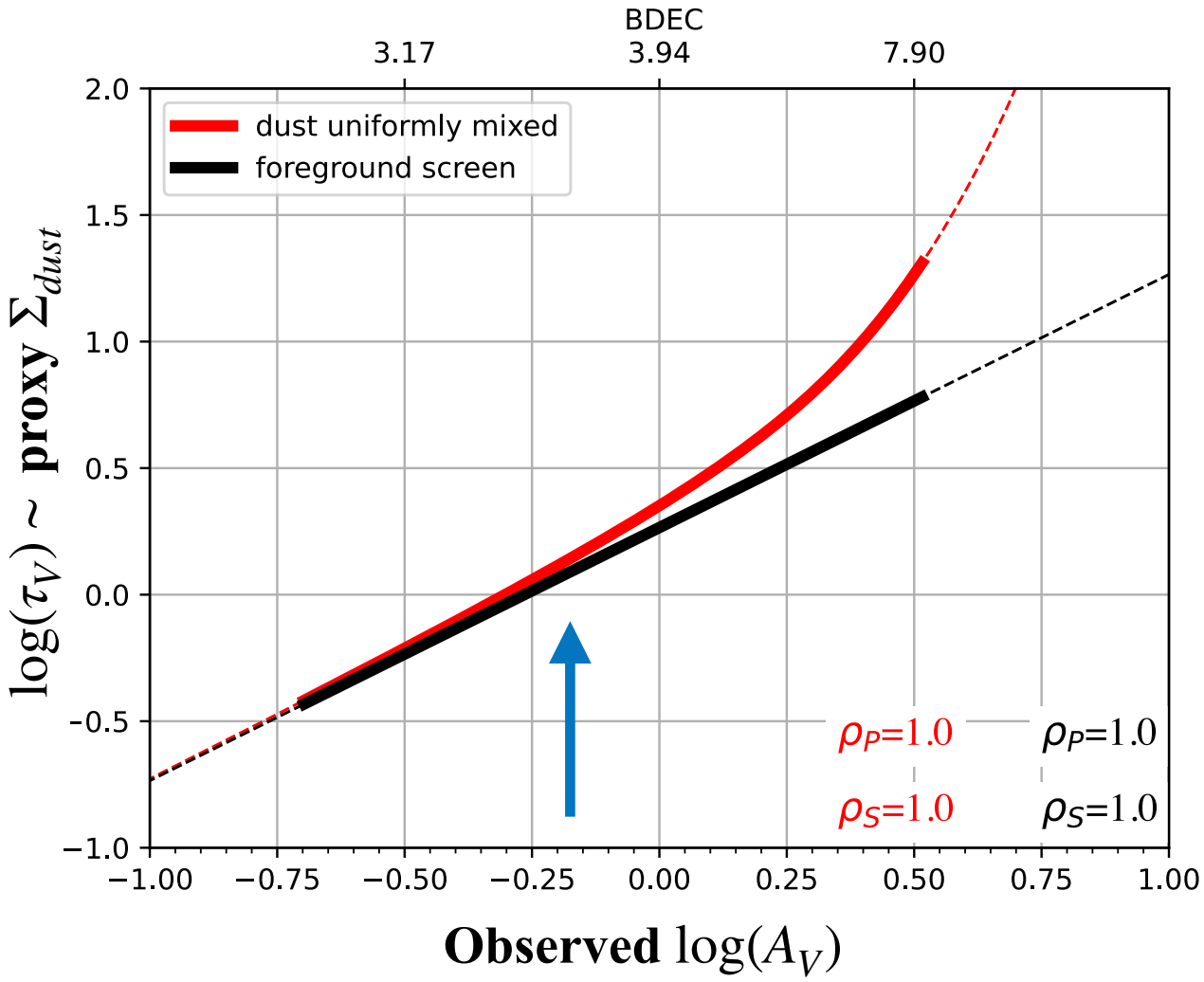
Dust optical depth τ_V VS A_V in different geometries





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See also Hunt et al. 2023

Summary

Using optical IFS and millimetre spectroscopy of local galaxies

- ★ Empirical relation cold gas from CO emission and dust extinction from $H\alpha/H\beta$ on kpc-scale
- ★ Variation with gas-phase metallicity (DGR or α_{CO} variation?)
- ★ Strong differences with previous work due to sample selection
- ★ $H\alpha/H\beta$ as a cold gas tracer in the absence of direct millimetre and sub-millimetre observations, test with EDGE-CALIFA data and example of resolved K-S relation.

Concas+ in prep.