THE NATURE OF THE [CII] EMISSION IN LENSED DUSTY STAR-FORMING GALAXIES FROM THE SPT SURVEY

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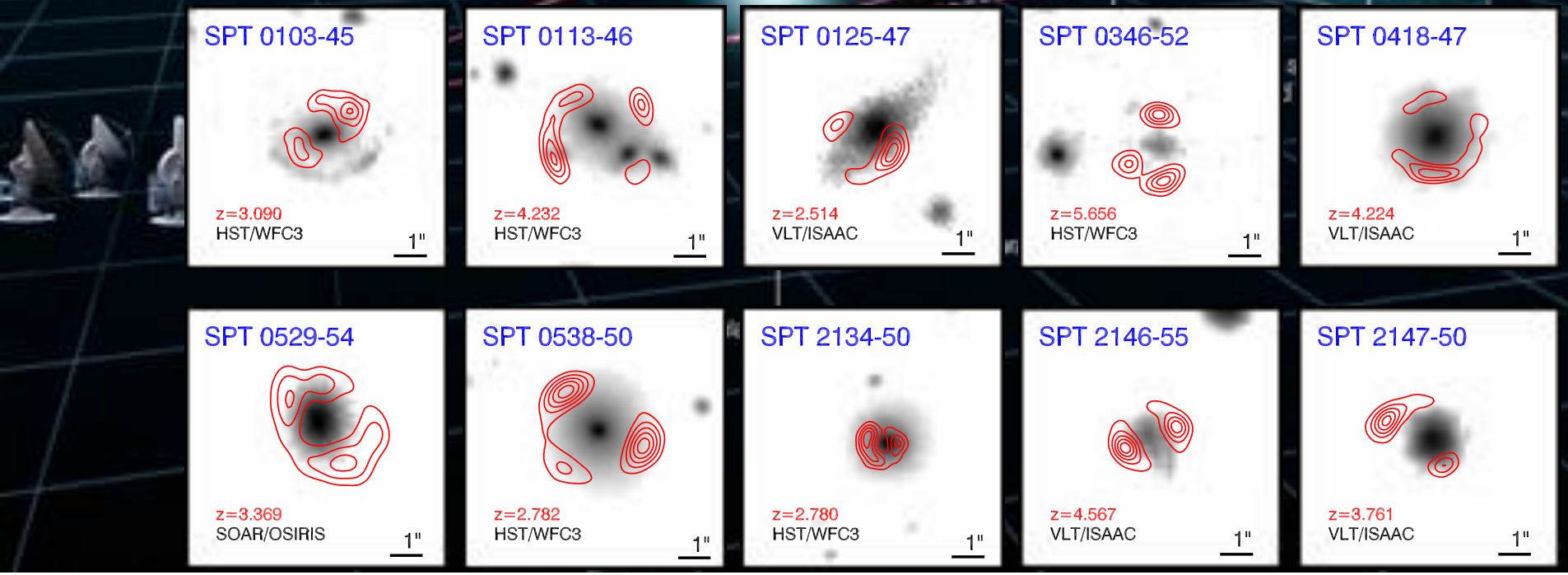
In collaboration with Carlos De Breuck and the SPT SMG collaboration

Back at the Edge of the Universe, Sintra, Portugal March 19th 2015

Lensed dusty starforming galaxies at high-z

z = 2.010 – 5.678



NIR (grey) and ALMA 870μm (red) images (J. Vieira et al. Nature 2013)

Motivation for follow up observations

Low-*J* CO: ATCA → 17/20 detections
[CII]: FLASH/APEX and *Herschel* SPIRE FTS → 17/20 detections

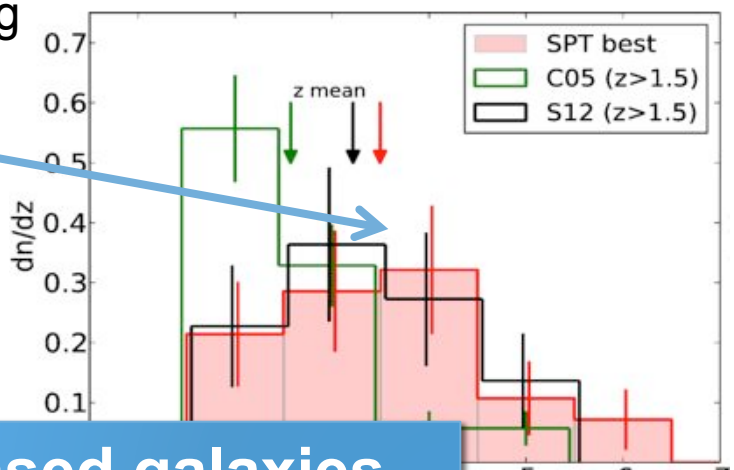
By studying [CII] and CO lines we wish to constrain the physical conditions of the ISM of high-*z* galaxies.

The lensing amplification of these bright dusty star forming galaxies makes this kind of study possible.

The redshift distribution of this sample covers the peak of the star formation history → the ideal sample for exploring evolutionary effects.

We wish to compare velocity profiles to explore the significance of differential lensing

We wish to confirm ambiguous ALMA redshifts (Weiss et al 2013)



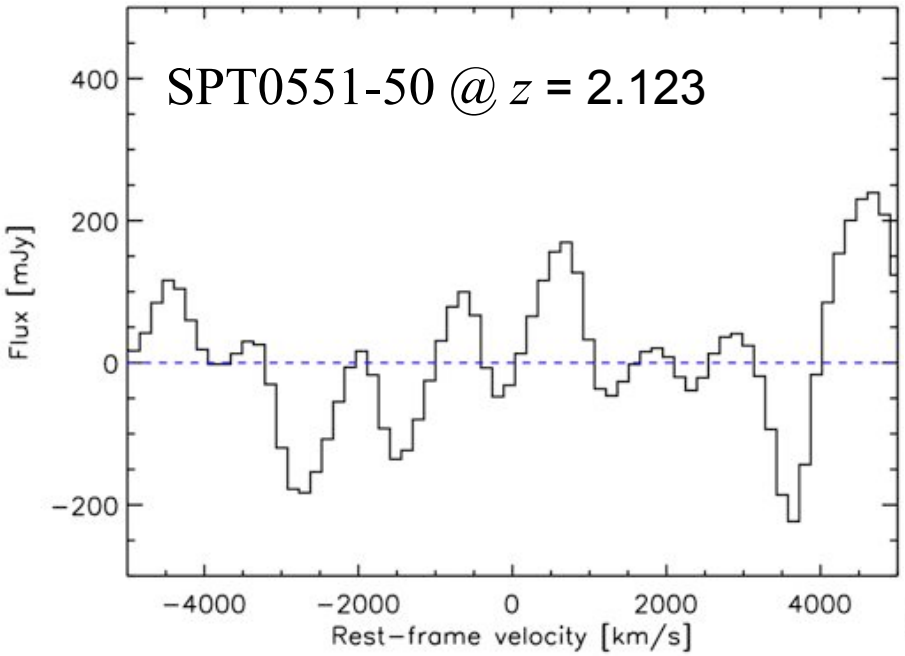
A. Weiss et al. 2013

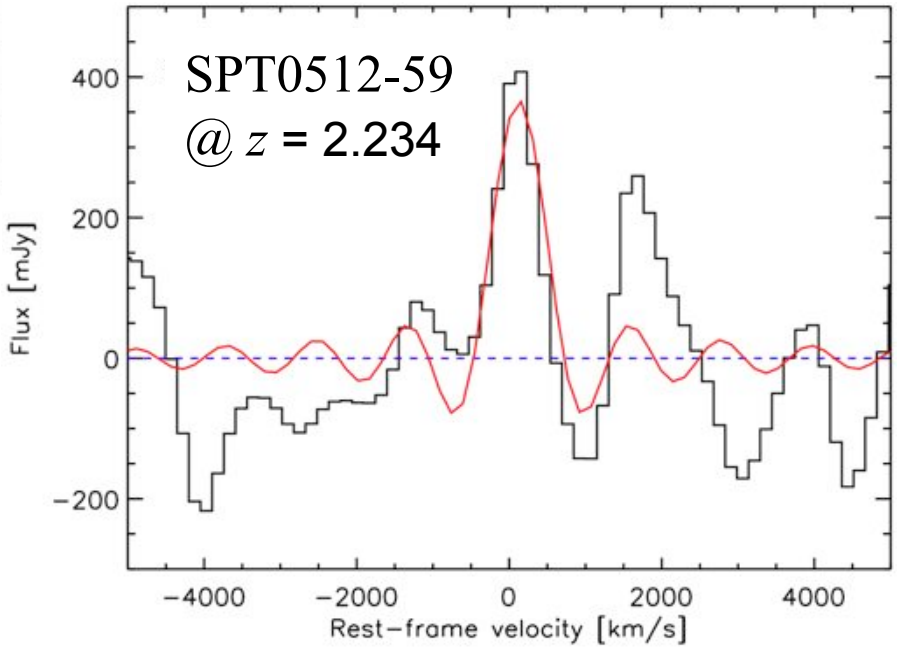
→ **Uniform selected sample of lensed galaxies**

FLASH @ APEX

17/20 sources @ z = 3.1 - 5.7 observed with FLASH during Max Planck time
→ 15 detections!

[CII] with *Herschel* SPIRE FTS

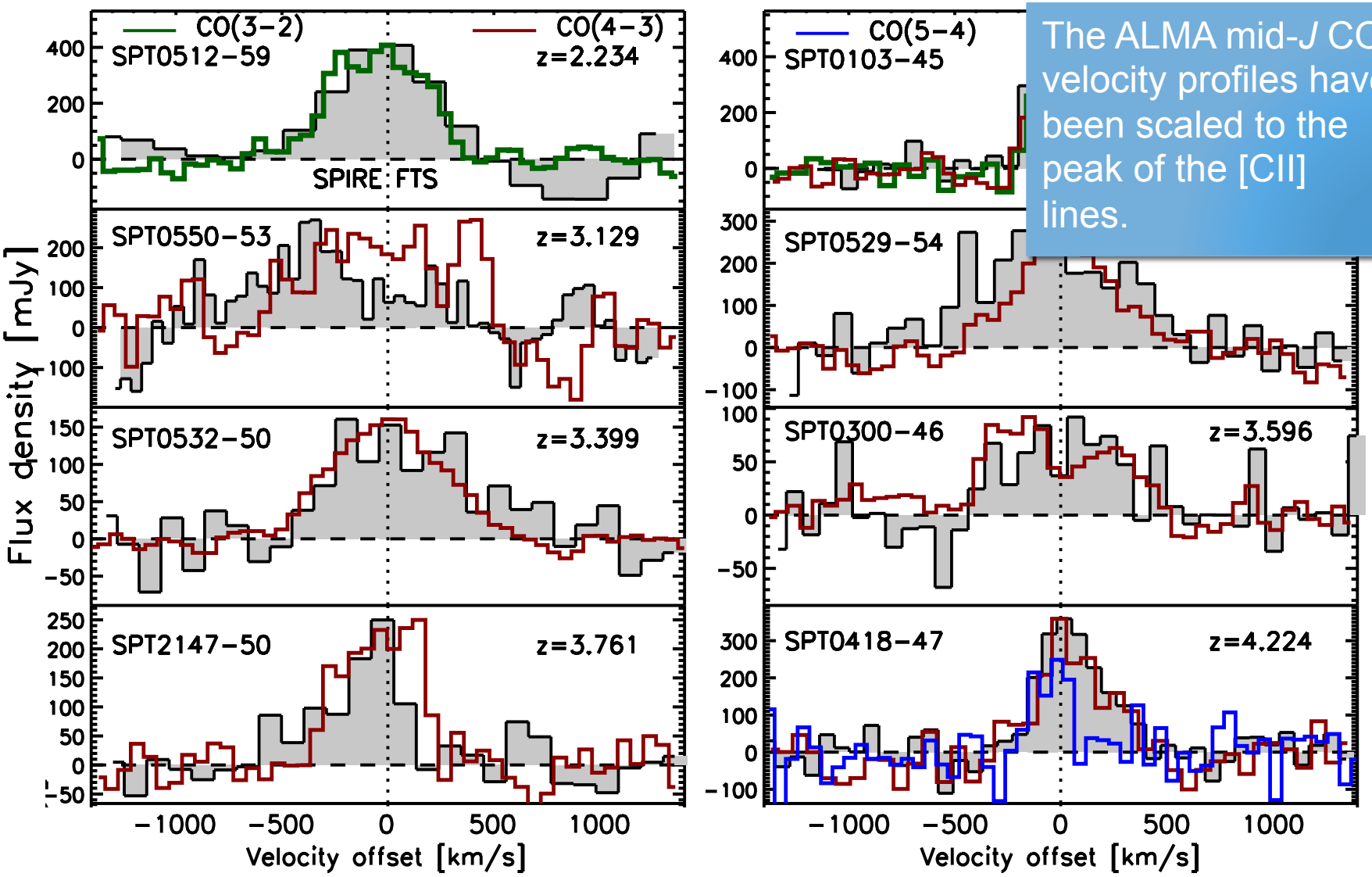




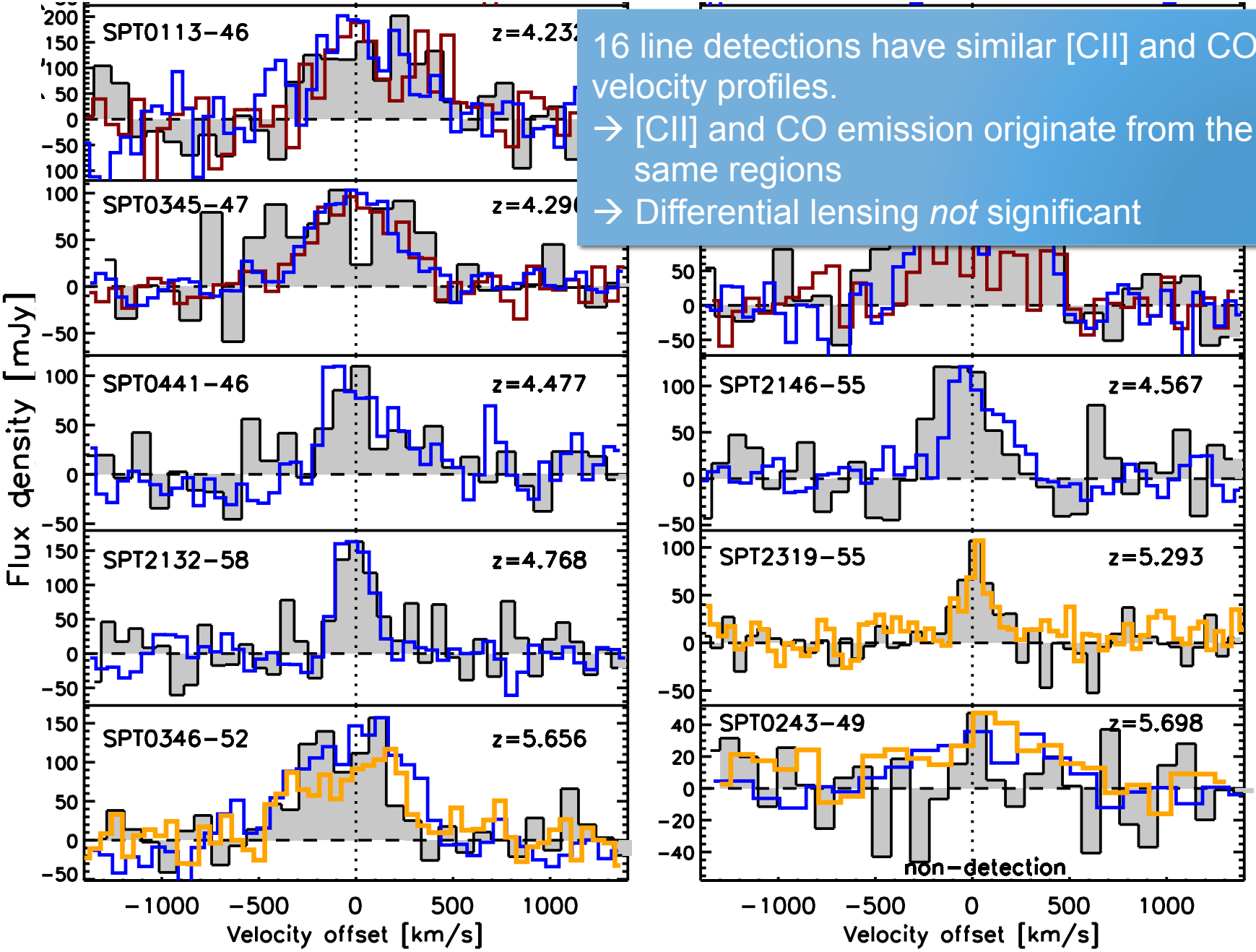
Sources @ z ~ 2 not observable from the ground.

APEX/FLASH can observe weaker lines at higher z

Velocity profiles – Comparing with ALMA



The ALMA mid-*J* CO velocity profiles have been scaled to the peak of the [CII] lines.


16 line detections have similar [CII] and CO velocity profiles.
→ [CII] and CO emission originate from the same regions
→ Differential lensing *not* significant
SPT0113−46
SPT0345−47
SPT0441−46
z=4.477
SPT2132−58
z=4.768
SPT0346−52
z=5.656
SPT2146−55
z=4.567
SPT2319−55
z=5.293
SPT0243−49
z=5.698
non−detection
Flux density [mJy]
Velocity offset [km/s]
Velocity offset [km/s]

Low-*J* CO with ATCA

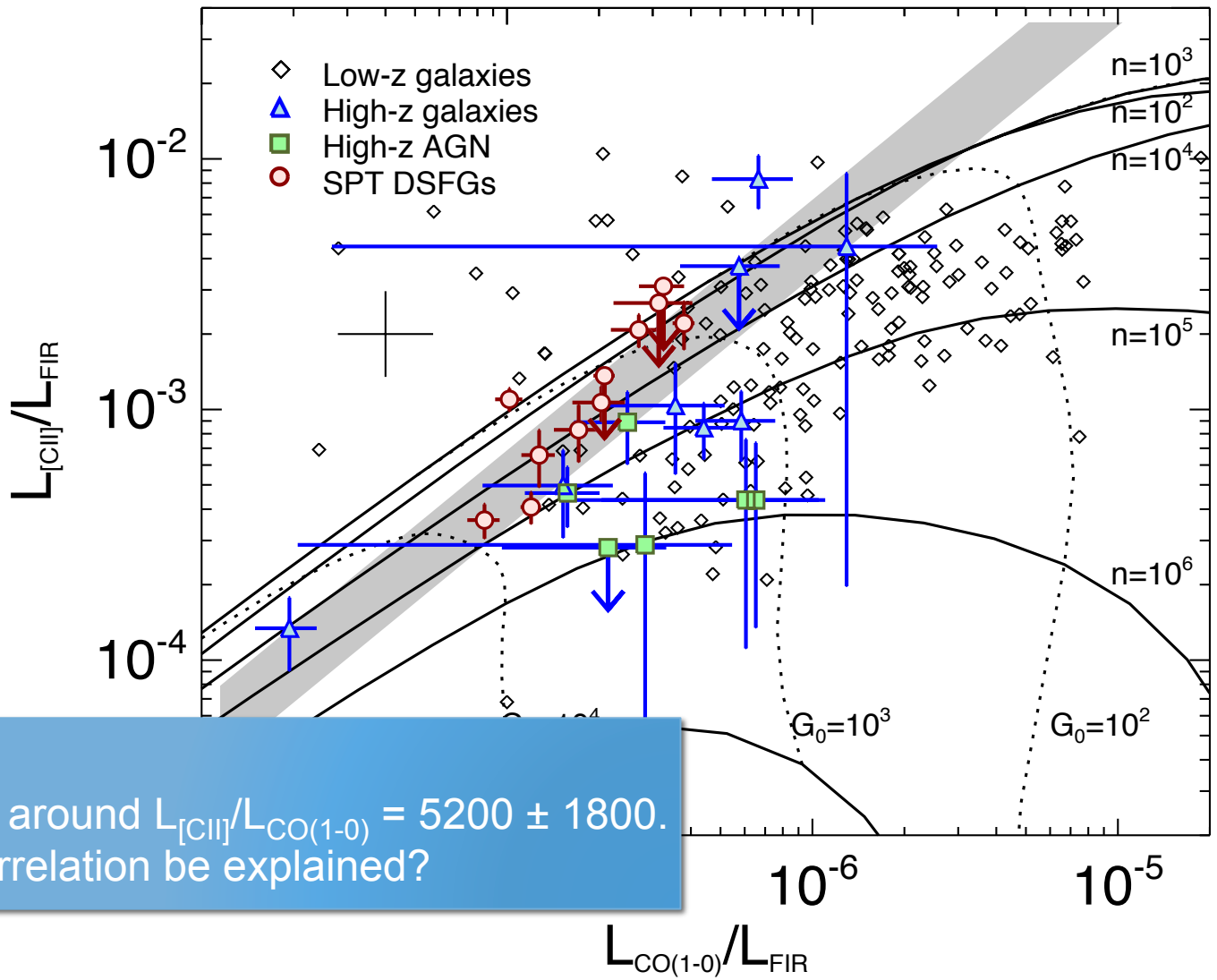
Low-J CO lines for 20 sources observed @ z = 2.0 - 5.7 observed with ATCA
→ 17 detections!

‘Diagnostic’ plot

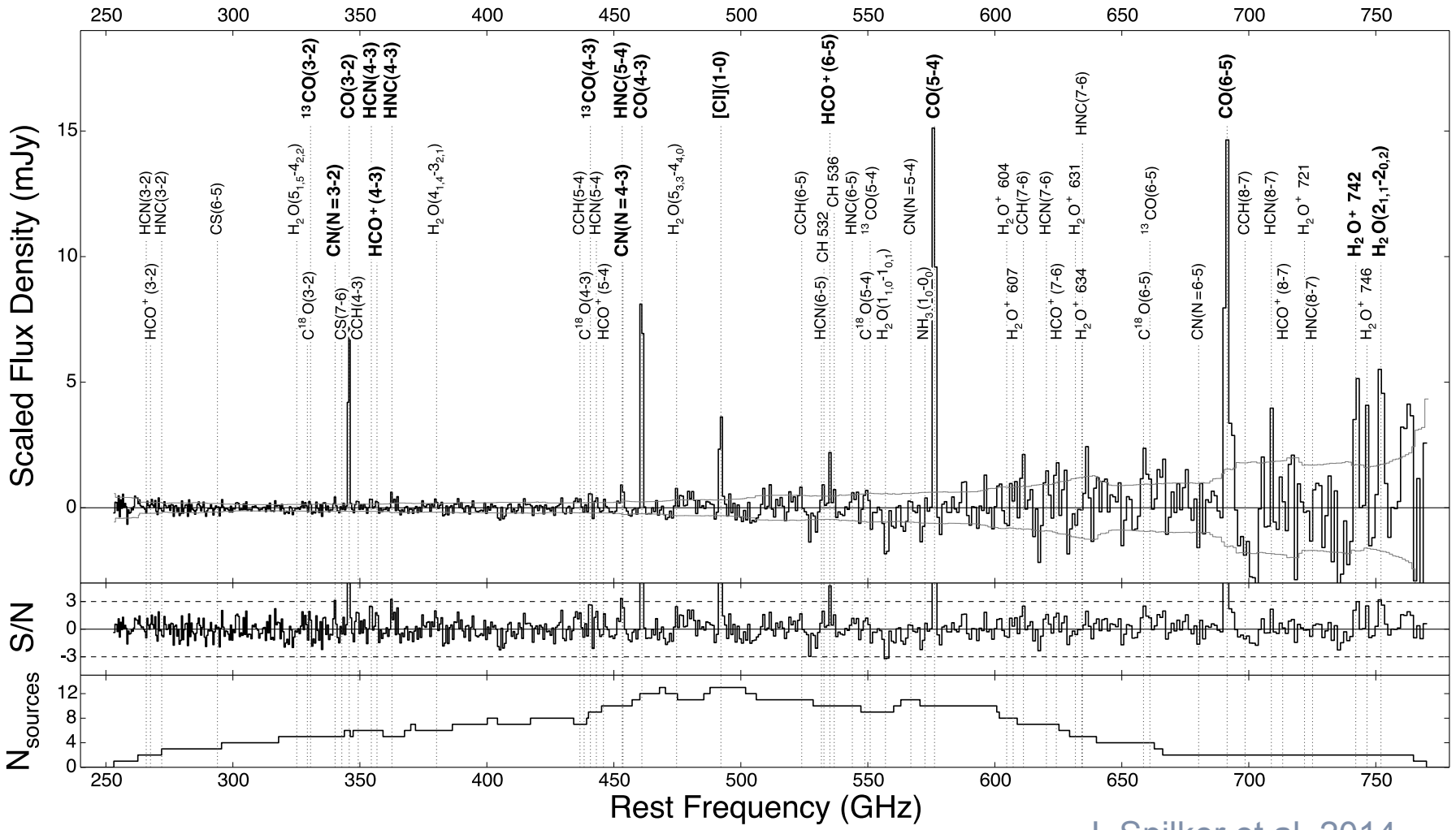
Photon dominated region (PDR) model

L_{FIR} determined in uniform manner for all

[CII] and CO luminosities integrated over the full galaxies



SPT sources:
Occupy an area around $L_{[CII]}/L_{CO(1-0)}$ = 5200 ± 1800.
How can this correlation be explained?



J. Spilker et al. 2014

Considering three cases:

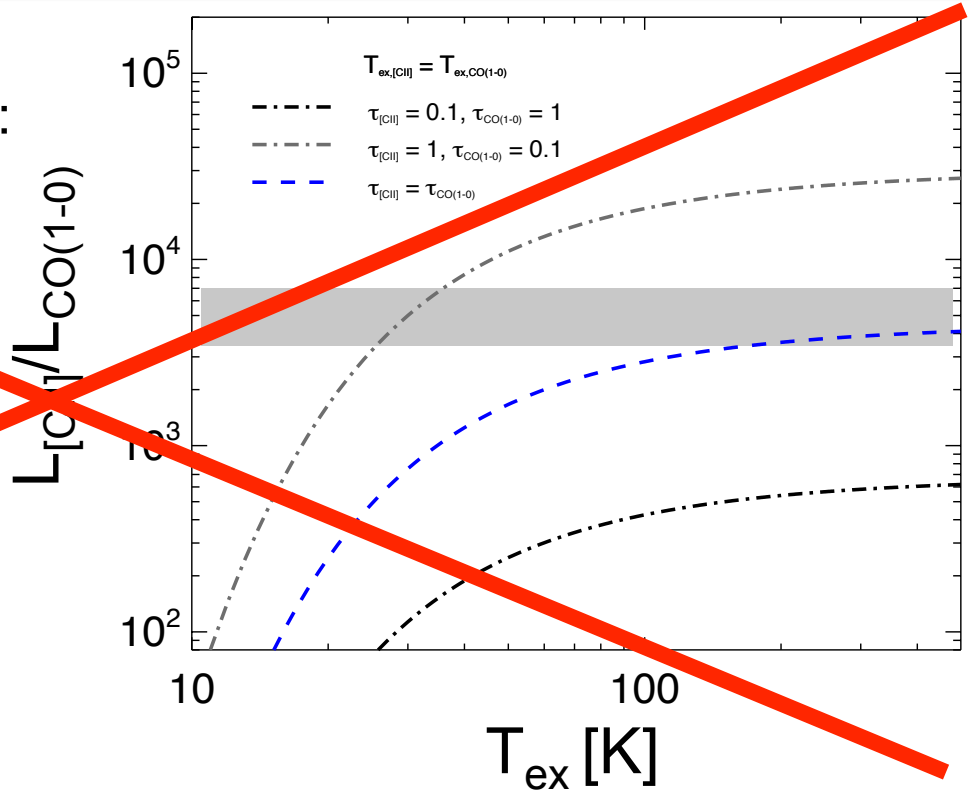
1. Optically thin [CII] and optically thick CO(1-0)
2. ~~Optically thick [CII] and optically thin CO(1-0)~~
3. Equal optical depth of [CII] and CO(1-0)

For Equal Excitation Temperatures

$$\frac{L_{[\mathrm{CII}]}}{L_{\mathrm{CO(1\text{-}0)}}} = \left(\frac{\nu_{[\mathrm{CII}]}}{\nu_{\mathrm{CO(1\text{-}0)}}}\right)^4 \times \frac{e^{h\nu_{\mathrm{CO(1\text{-}0)}}/hT_{\mathrm{ex,CO(1\text{-}0)}}} - 1}{e^{h\nu_{[\mathrm{CII}]}/hT_{\mathrm{ex,[CII]}}} - 1} \cdot \frac{1 - e^{-\tau_{[\mathrm{CII}]}}}{1 - e^{-\tau_{\mathrm{CO(1\text{-}0)}}}}$$

For equal excitation temperatures:

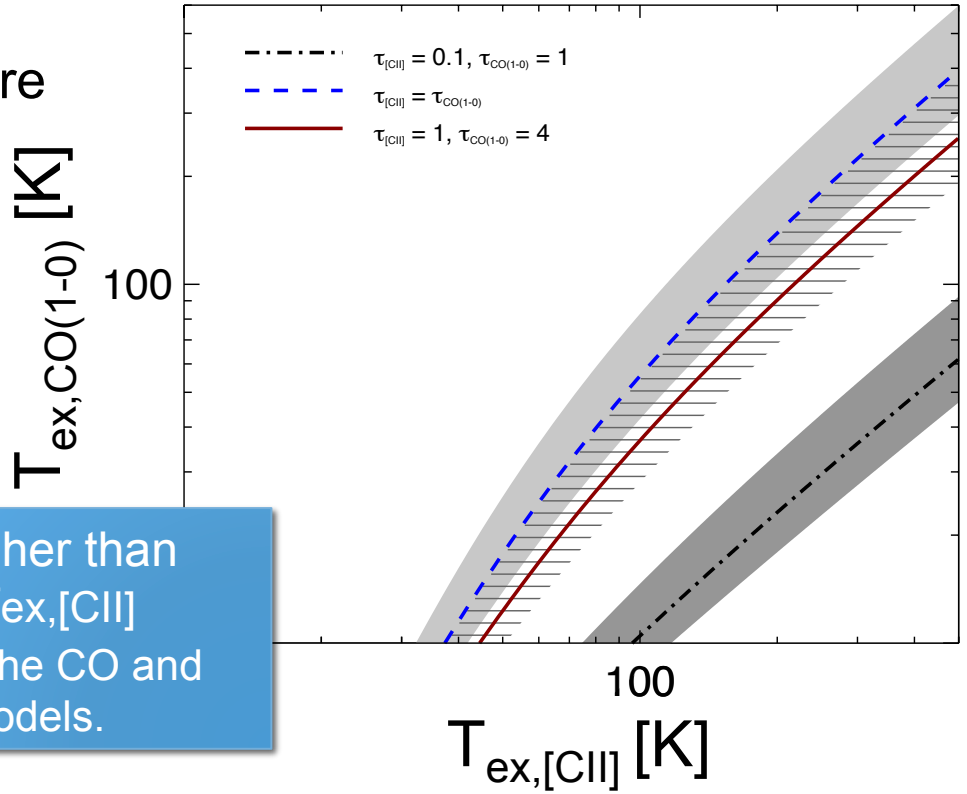
Only for equal optical depth does the luminosity ratio reach the observed range, but only for high T_{ex}



For Different Excitation Temperatures

$$\frac{L_{[\mathrm{CII}]}}{L_{\mathrm{CO(1\text{-}0)}}} = \left(\frac{\nu_{[\mathrm{CII}]}}{\nu_{\mathrm{CO(1\text{-}0)}}}\right)^4 \times \frac{e^{h\nu_{\mathrm{CO(1\text{-}0)}}/hT_{\mathrm{ex,CO(1\text{-}0)}}} - 1}{e^{h\nu_{[\mathrm{CII}]}/hT_{\mathrm{ex,[CII]}}} - 1} \cdot \frac{1 - e^{-\tau_{[\mathrm{CII}]}}}{1 - e^{-\tau_{\mathrm{CO(1\text{-}0)}}}}$$

The CO(1-0) excitation temperature as function of the [CII] excitation temperature.



The [CII] excitation temperature is higher than the CO(1-0) excitation temperature: Tex,[CII] >Tex,CO(1-0). Indicating a separation of the CO and [CII] emitting gas similar to simple PDR models.

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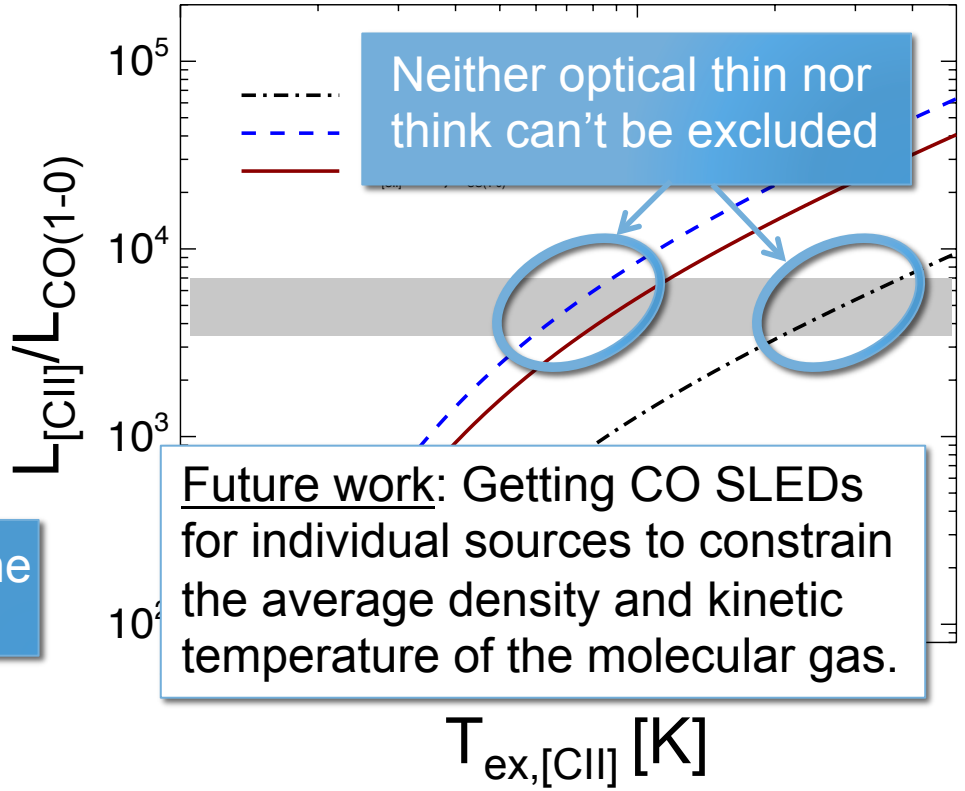
For a fix CO(1-0) excitation temperature of ~ 35K – from CO SLEDs (Spilker et al. 2014)

The luminosity ratio reaches with in the observed range for Tex,[CII]~60-90K



Future work: Getting CO SLEDs for individual sources to constrain the average density and kinetic temperature of the molecular gas.

Summary

A uniform selected sample of high-z lensed dusty star forming galaxies - making a more reliable comparison between physical condition of the ISM in galaxies over the redshift range z ~ 2 - 5.7 possible.

The lensing of these SPT sources makes it possible to study both the atomic and molecular ISM, via photon dominated regions at high-z.

Bright [CII] lines have been detected for 17/20 sources.
Bright low-J CO lines have been detected for 17/20.
→ 11 sources having both detections of [CII] and low-J CO.

[CII] and ALMA mid – J CO velocity profiles are statistically similar
→ Suggest that the [CII] and CO emission originate from the same regions and that differential lensing is not significant

The SPT DSFGs have a fitted ratio of ~5200±1800, suggesting low to moderate optical depth of [CII] ($\tau \lesssim 1$) and higher excitation temperature of [CII] then CO(1-0). This implies a medium of 'separated' CO(1-0) and [CII] emitting gas ~ similar to the structure for PDR models.

Thank you!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