

# Resolving molecular gas at $\sim 500$ pc in a star forming disk galaxy at $z \sim 2$

Presenter: Drew Brisbin<sup>1</sup>

February, 2019

*Linking Galaxies From the Epoch of Initial Star Formation to Today*

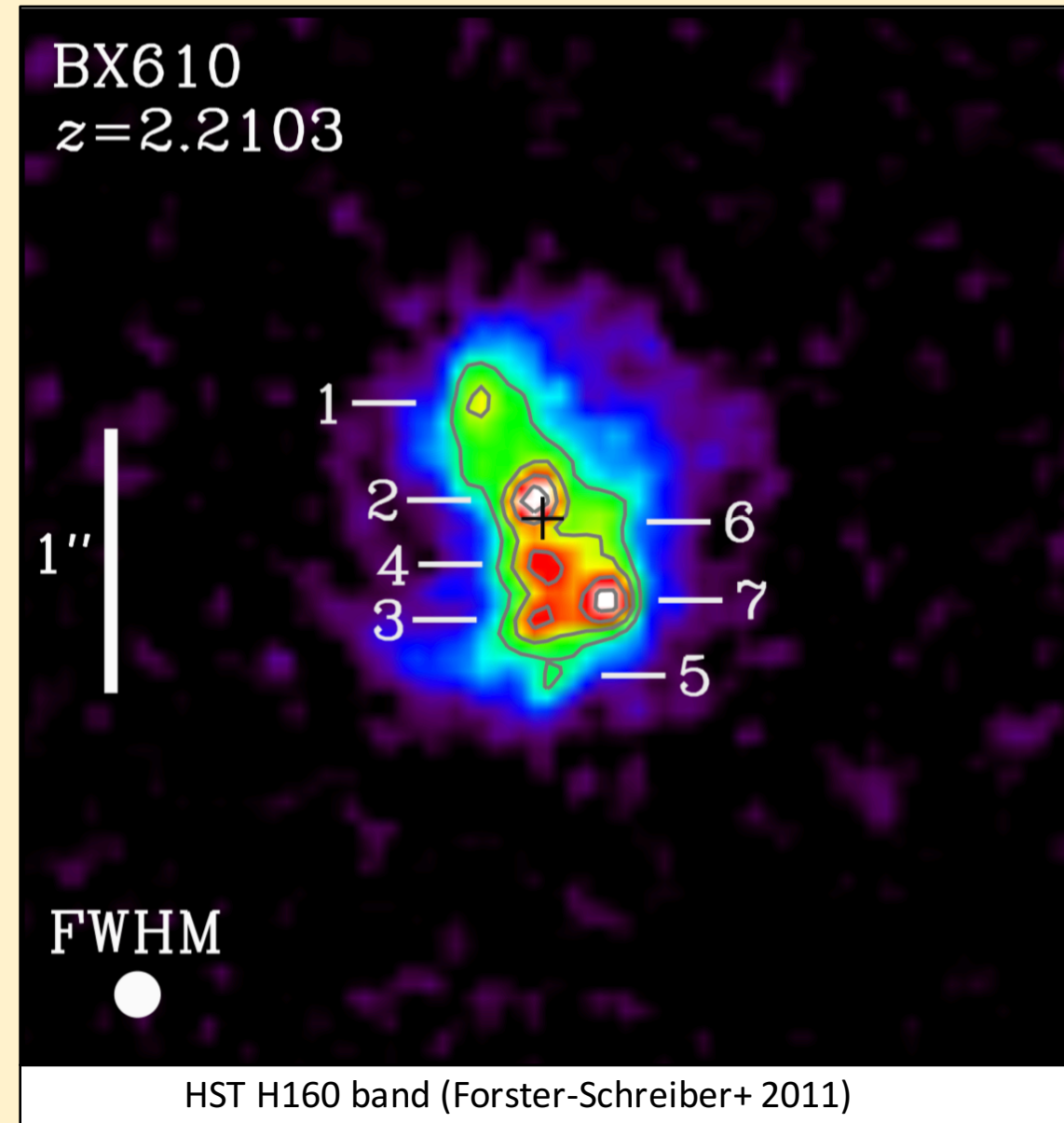
Sydney Australia

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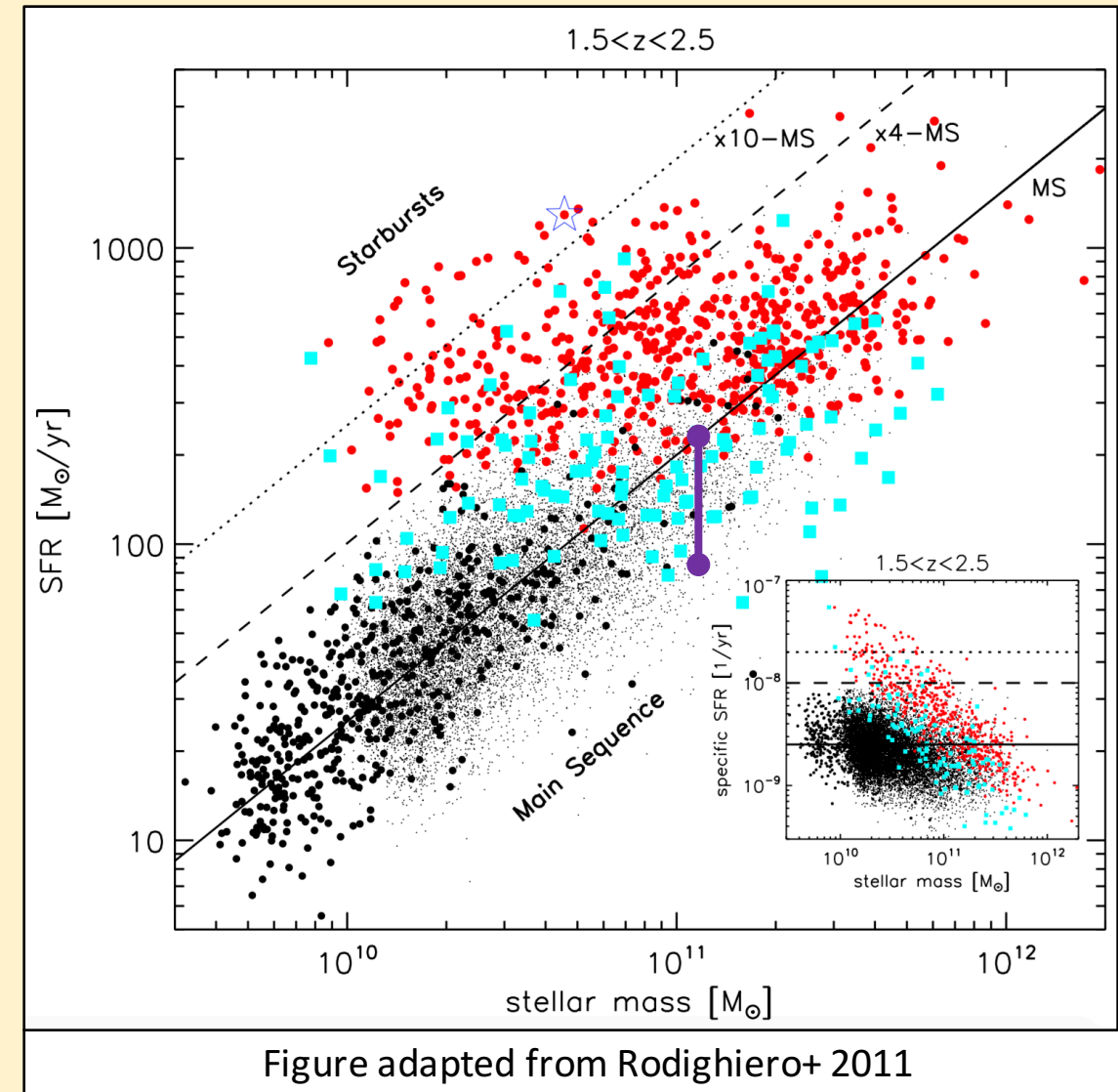
# BX610

- Massive star forming disk galaxy
  - Early universe:  $z=2.2103$
  - previously detected by HST
  - SINFONI  $H\alpha$
  - $SFR \sim 60-200 M_{\odot} \text{ yr}^{-1}$
- (Forster Schreiber+ 2014, 2018; Tacconi+ 2013)



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  - $SFR \sim 60-200 M_{\odot} \text{yr}^{-1}$
- (Forster Schreiber+ 2014, 2018; Tacconi+ 2013)
- ‘normal’ star forming galaxy?
  - How does it compare to a compact star forming galaxy (cSFG)?
  - **Crucial stepping stone to understand more typical galaxies in early universe**

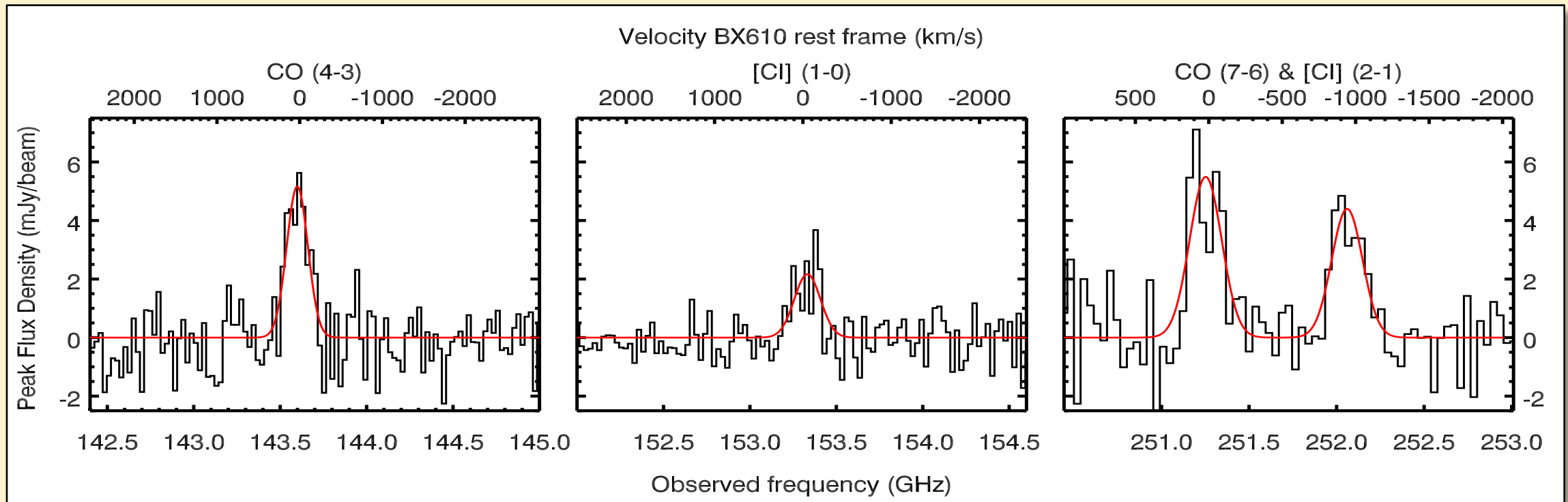


# Campaign: investigate molecular + atomic gas

- Full campaign: PdBI ( $\sim 2'' = 17$  kpc), ALMA compact ( $\sim 0.3'' = 2.5$  kpc), ALMA extended ( $\sim 0.055'' = 0.5$  kpc)
- Probe [Cl] x2
  - ( $^3P_1 - ^3P_0$ )  $\nu_{\text{rest}} = 492.2$  GHz
  - ( $^3P_2 - ^3P_1$ )  $\nu_{\text{rest}} = 809.3$  GHz
- Probe CO (7-6) & (4-3) ( $\nu_{\text{rest}} = 461.0$  &  $806.7$  GHz)
- Previous integrated galaxy observations of CO (1-0) and CO (3-2) (Bolatto+ 2015)

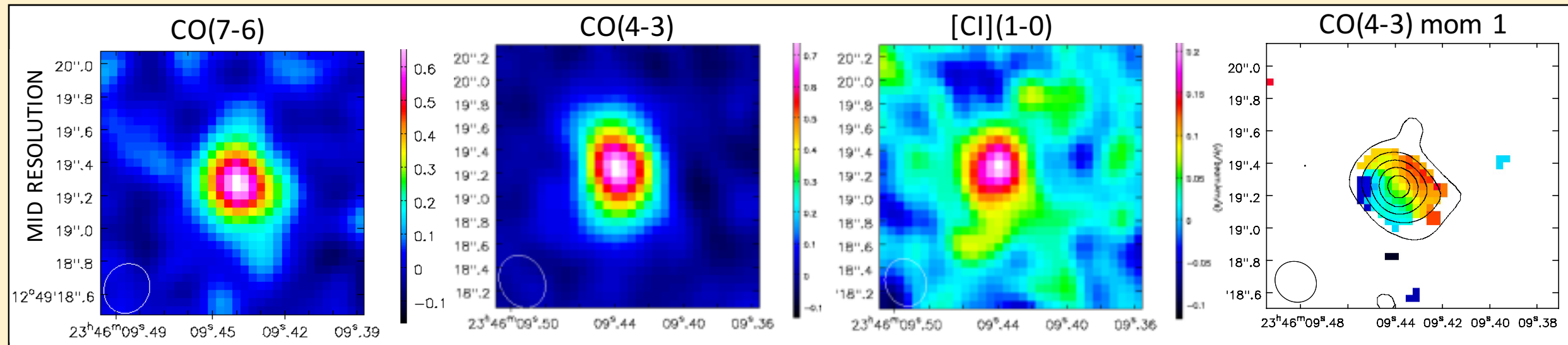
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- Lines detected strongly



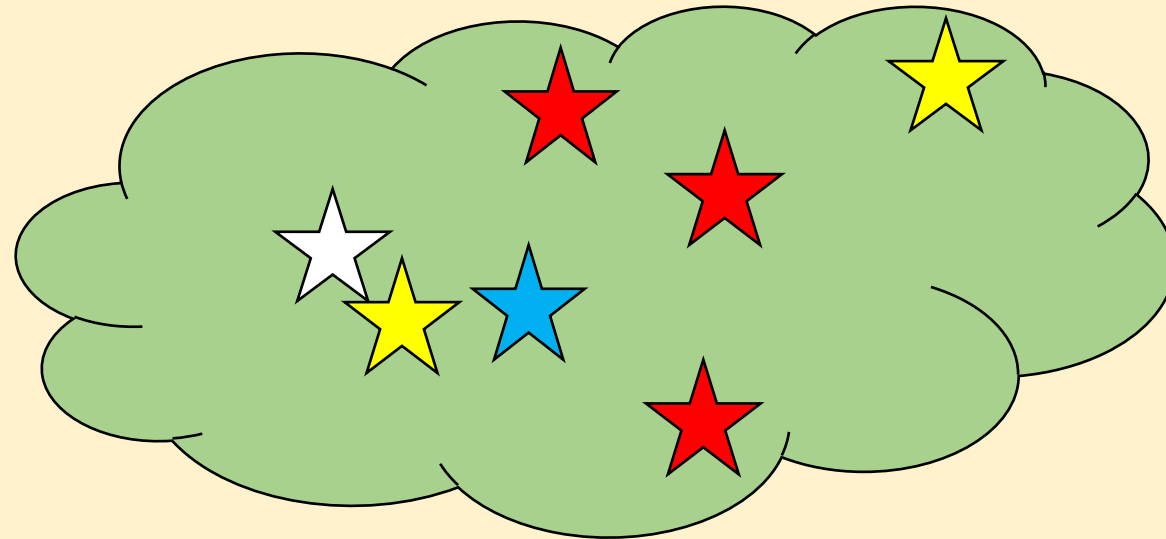
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- Full campaign: PdBI ( $\sim 2'' = 17$  kpc), ALMA compact ( $\sim 0.3'' = 2.5$  kpc), ALMA extended ( $\sim 0.055'' = 0.5$  kpc)
- Lines detected strongly
- Marginally resolved,  $\sim 3$  kpc
- Smooth rotation



# How much cold gas?

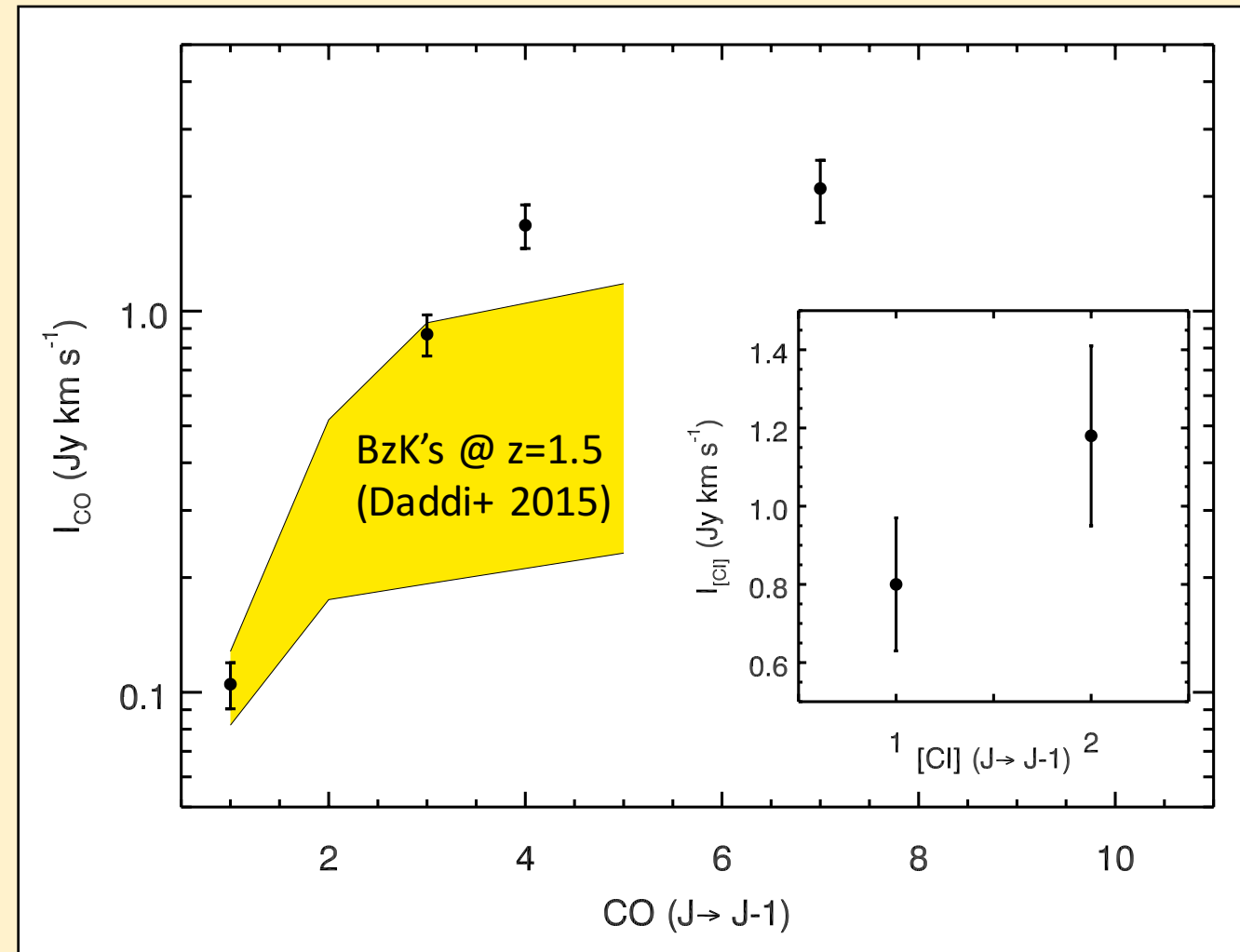
- $M_{\text{gas}} (\text{H}_2 + \text{He})$ 
  - CO:  $1.1 \cdot 10^{11} M_{\odot}$ 
    - $\alpha_{\text{CO}} = 4.36 (\text{K km/s pc}^2)^{-1}$
  - [C I]:  $1.4 \cdot 10^{11} M_{\odot}$
  - Dust:  $1.3 \cdot 10^{11} M_{\odot}$
- $\tau_{\text{dep}} = 0.6 - 2.2 \text{ Gyr}$





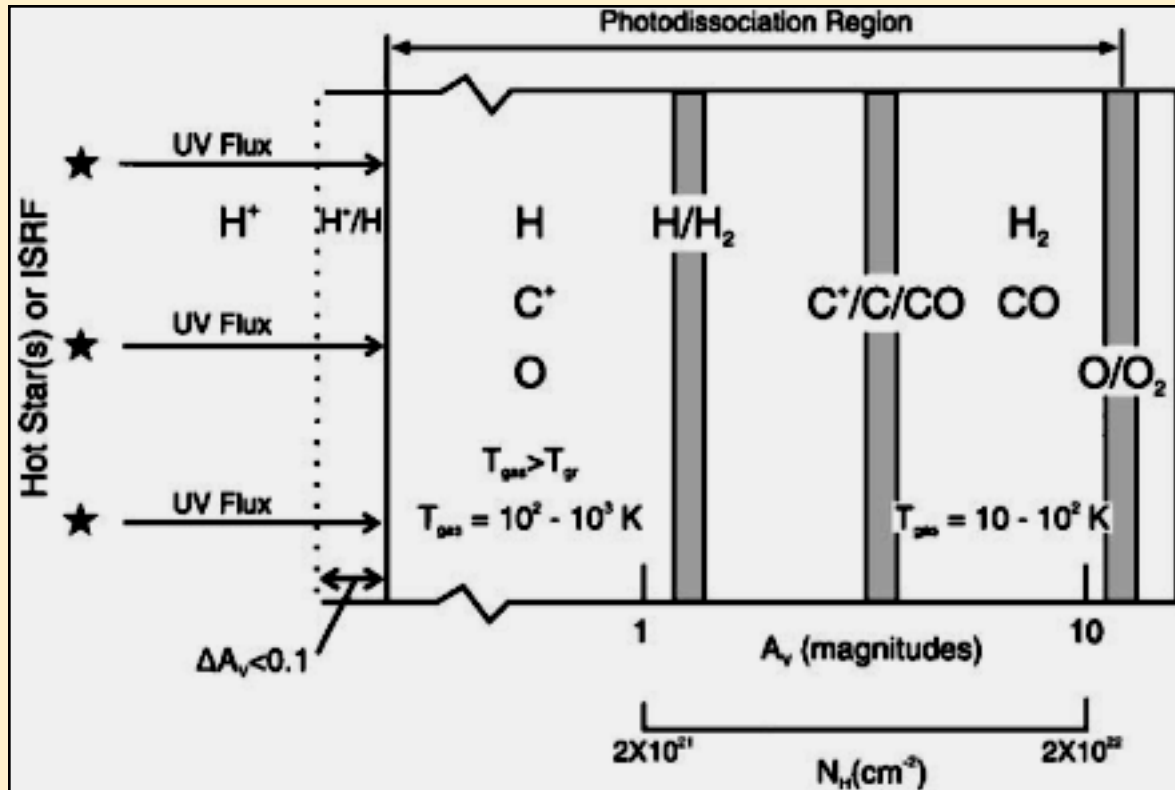
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- $\tau_{\text{dep}} = 0.6 - 2.2 \text{ Gyr}$
- High J CO emission  
→ Presence of excited gas

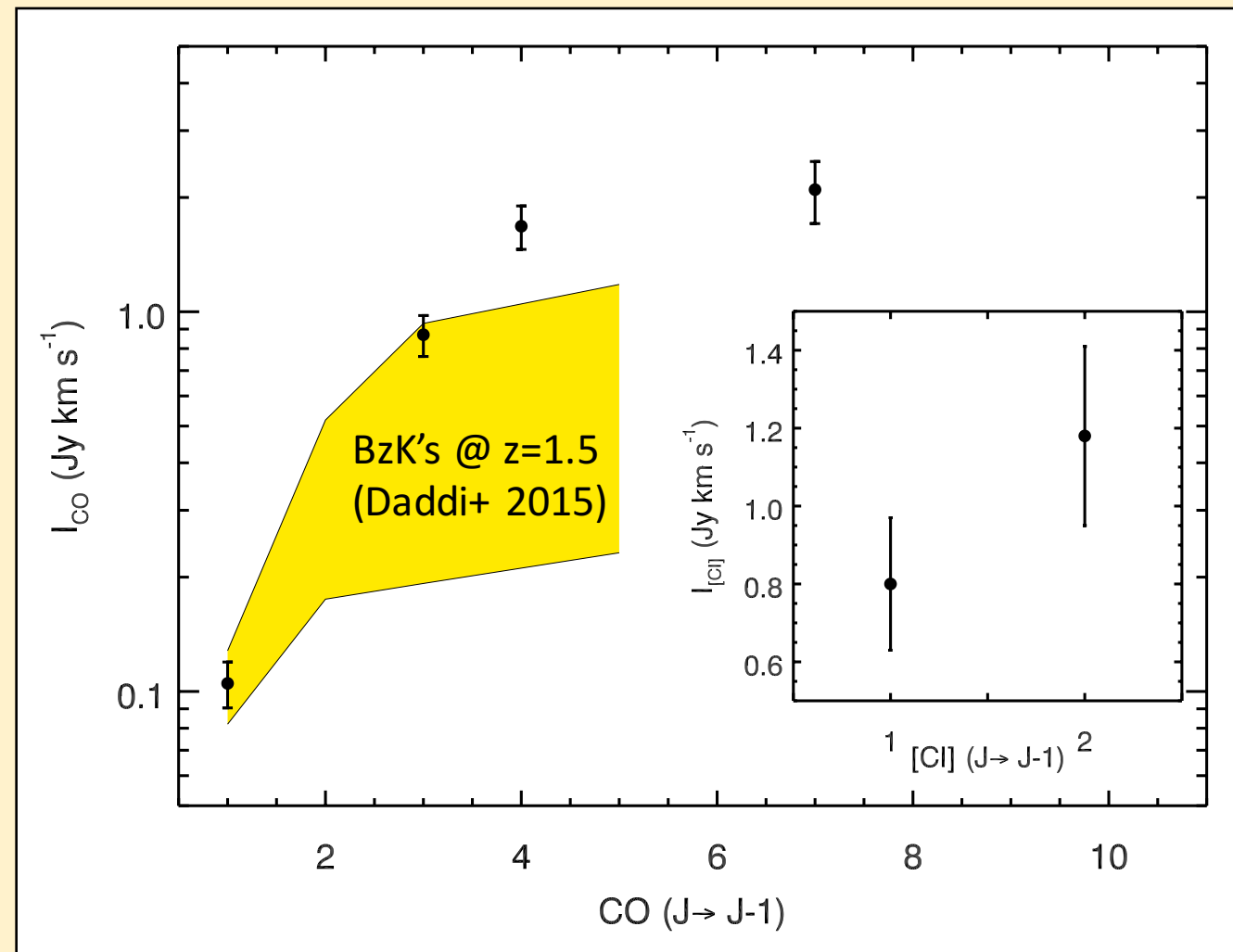




# Gas modeling: Photon Dominated Regions



Hollenbach & Tielens 1997 ARAA 35 179



# Gas modeling

A clue:  $-4.4 < \text{Log}[\text{CO}(7-6)/L_{\text{IR}}] < -3.5$

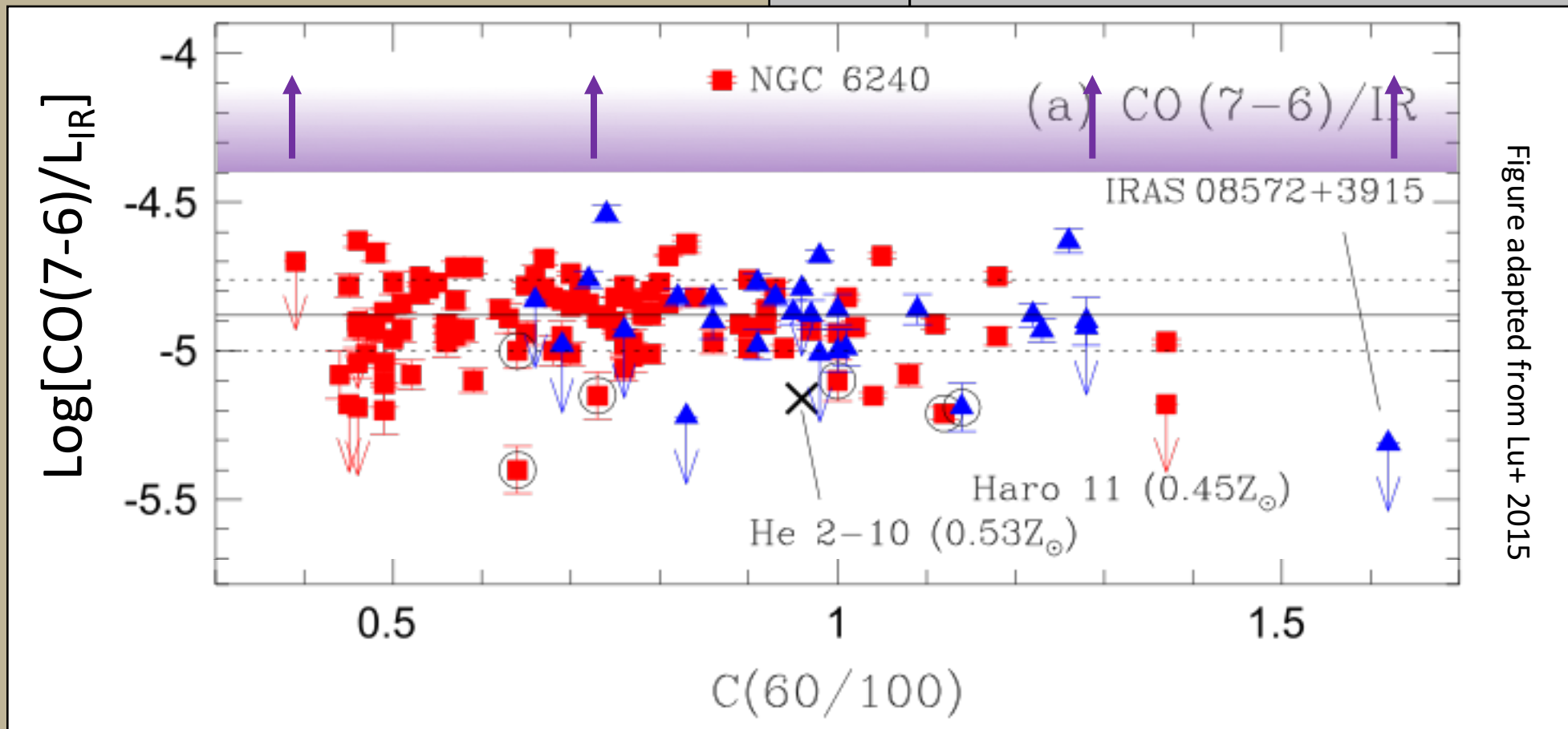
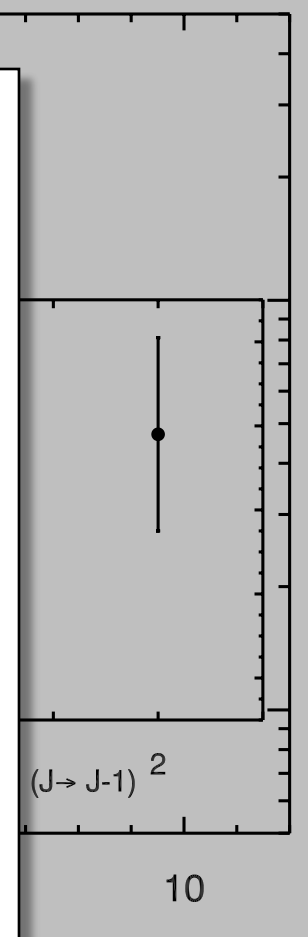
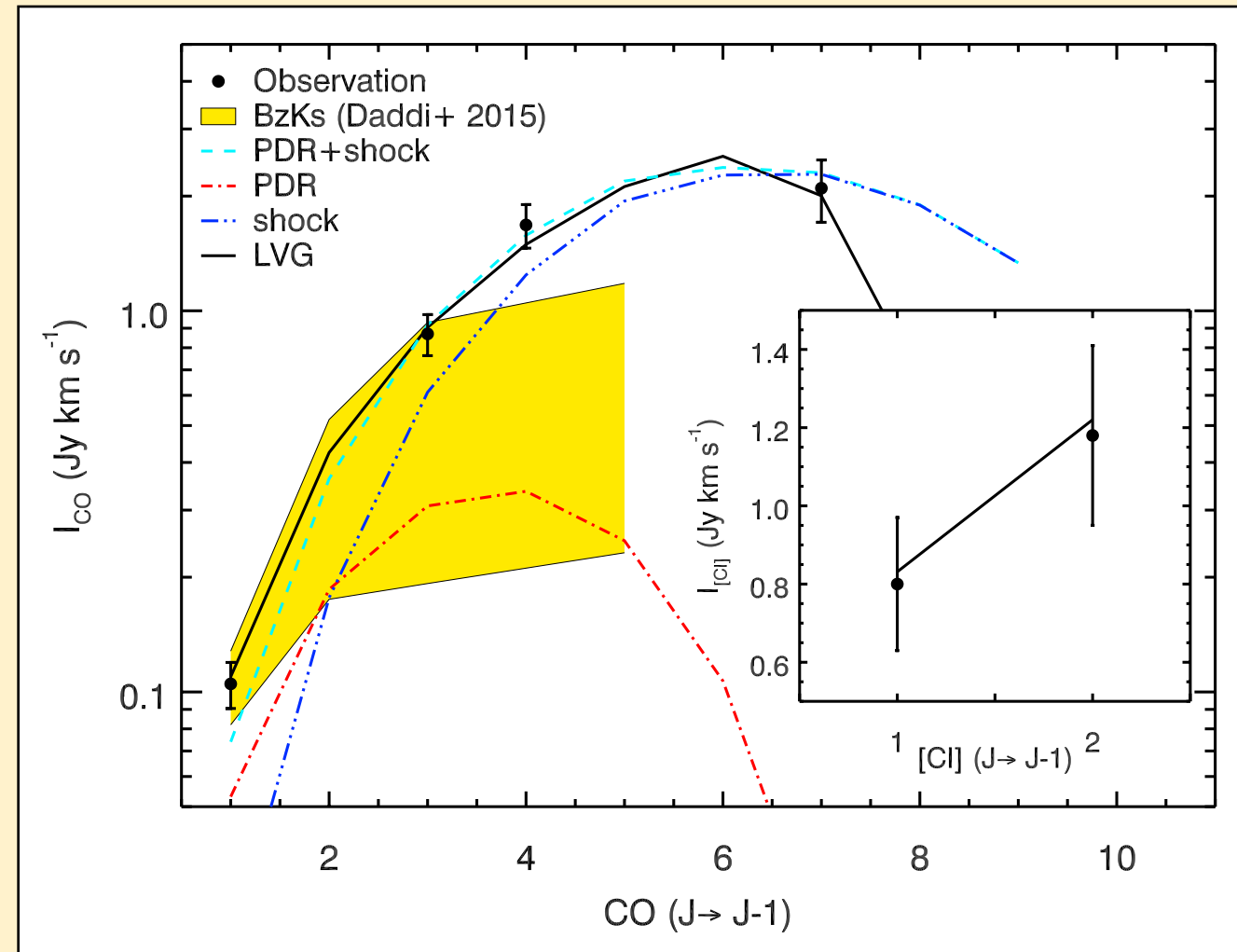
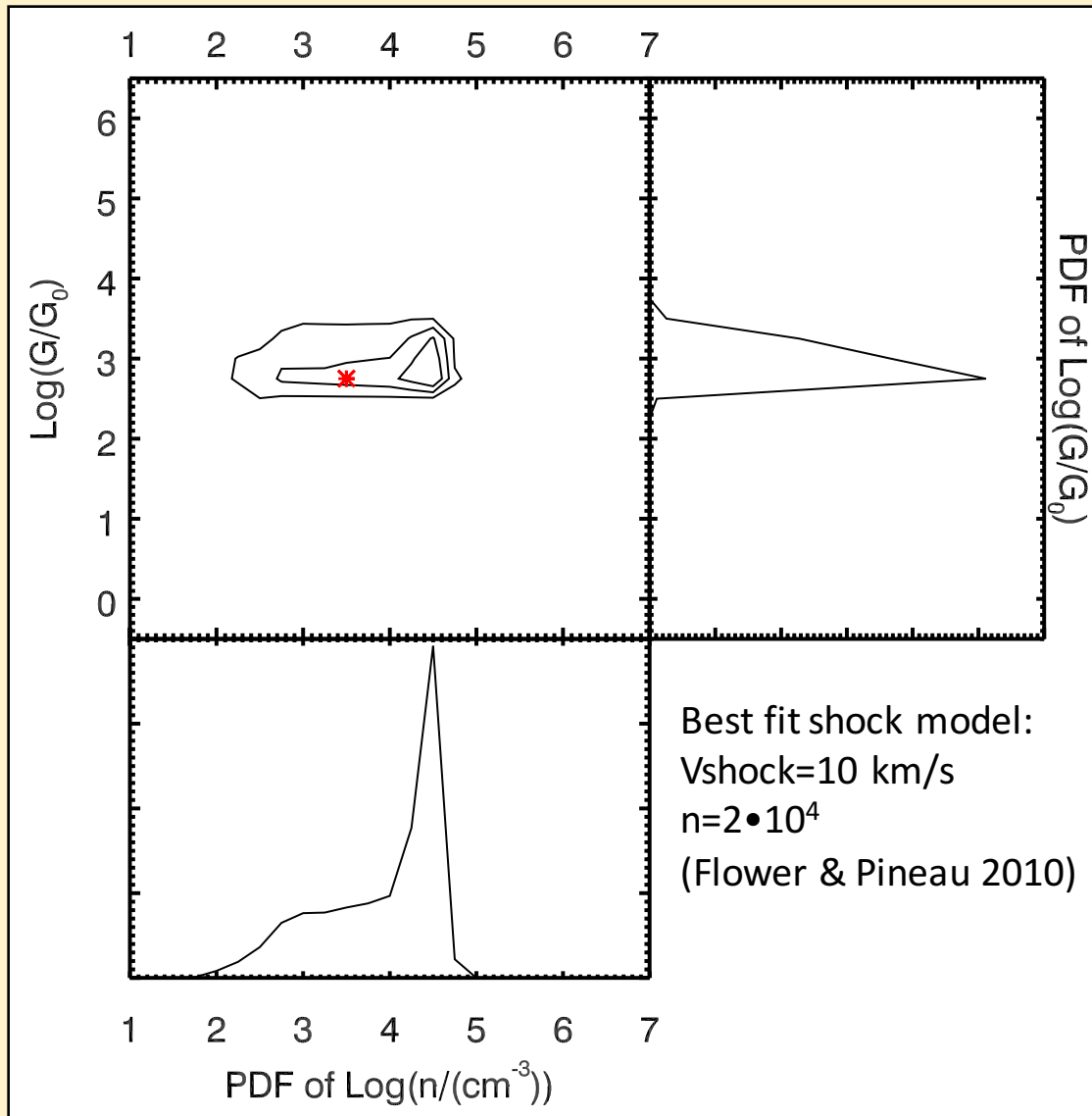


Figure adapted from Lu+ 2015



# Gas modeling: PDR+shocks



# What is BX610?

	<u>Compact star forming galaxy</u>	<u>BX610</u>
Line widths:	~600 km/s	~300 km/s
Spatial extent:	~2 kpc ( $M_*$ dependent)	3-5 kpc
$\tau_{\text{dep}}$ :	~100 Myr	600-2200 Myr

# What is BX6

Line widths  
Spatial extent

$\tau_{\text{dep}}$

yr

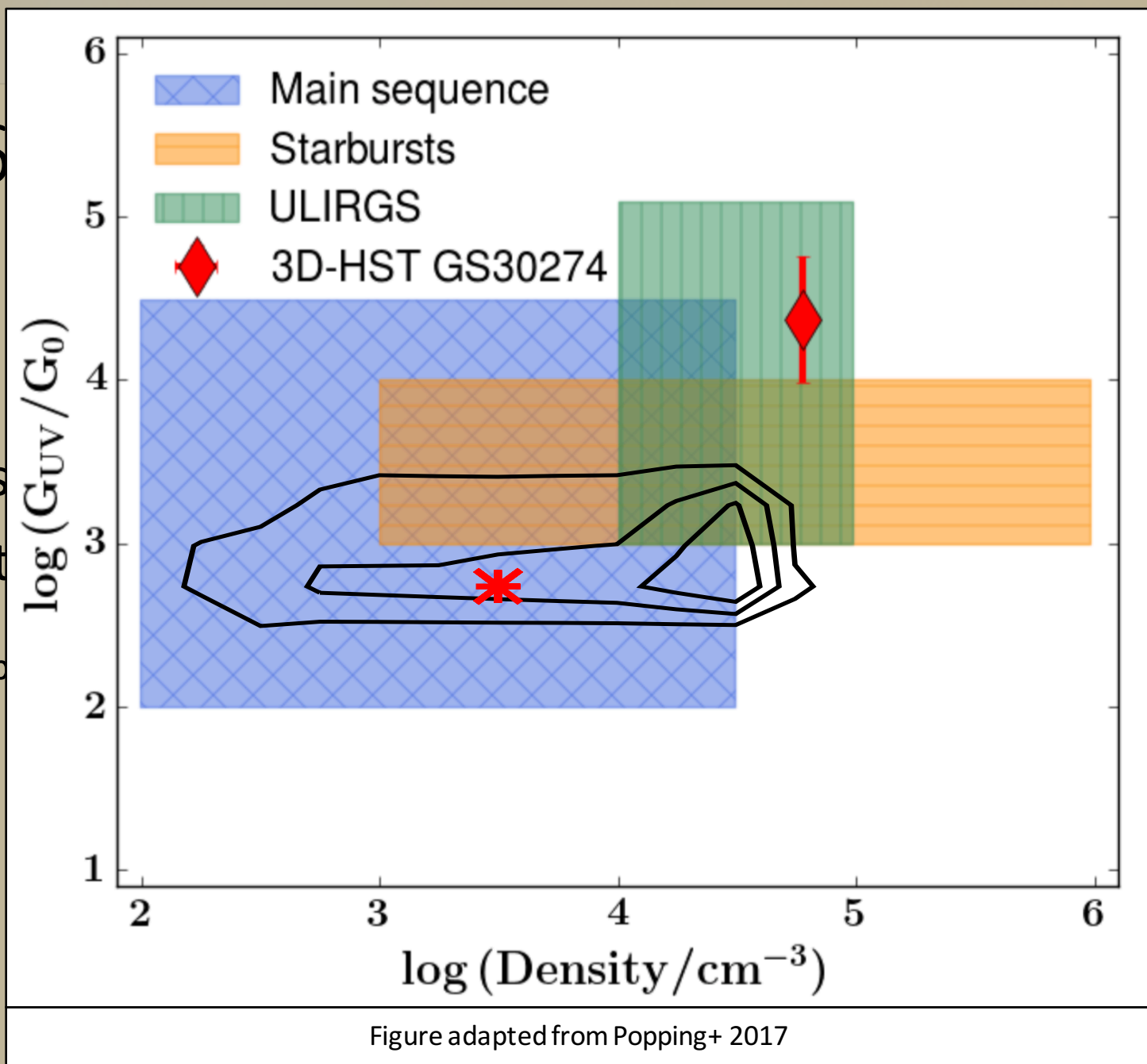



Figure adapted from Popping+ 2017

# What is BX610?


	<u>Compact star forming galaxy</u>	<u>BX610</u>
Line widths:	~600 km/s	~300 km/s
Spatial extent:	~2 kpc ( $M_*$ dependent)	3-5 kpc
$\tau_{\text{dep}}$ :	~100 Myr	600-2200 Myr
UV field:	High (G/G0 $\sim 10^5$ )	Med ( $10^3$ )
Density:	High ( $n \sim 10^4$ )	Med ( $10^{3.5}$ )

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-  High res (VERY PRELIMINARY!)
  - $\sim 500$  pc
  - Only CO (4-3) and [Cl] ( $^3P_1 - ^3P_0$ )



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# Campaign:

- Full campaign: P  
ALMA extended
-  High res (VEI)
  - ~500 pc
  - Only CO (4-3) a

gas

c),

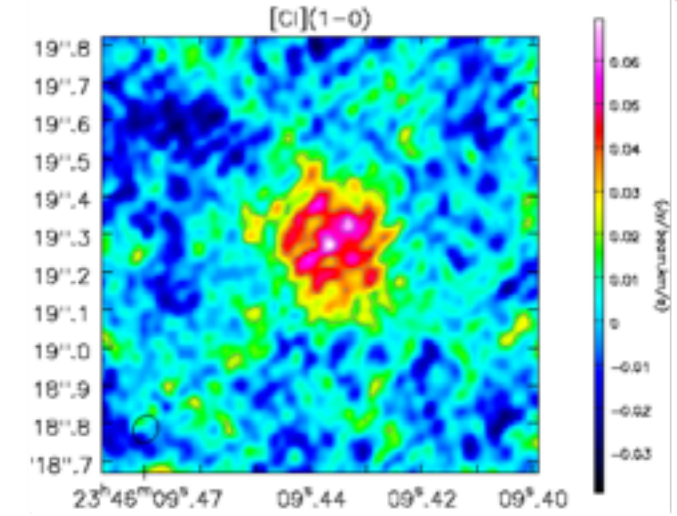
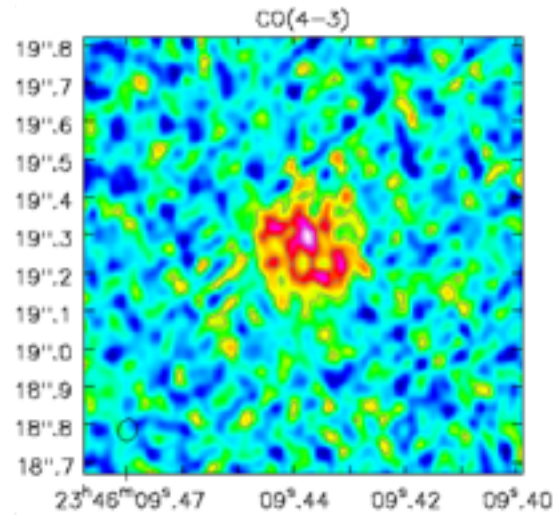
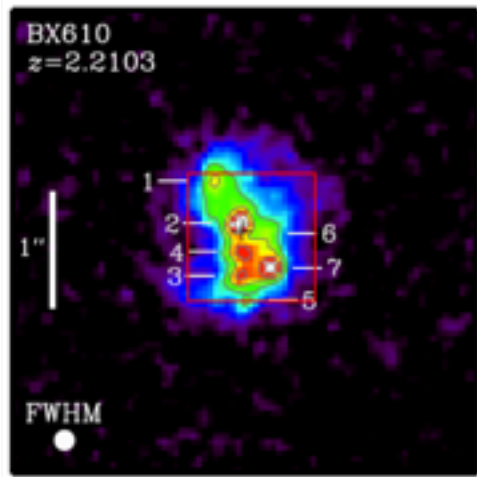
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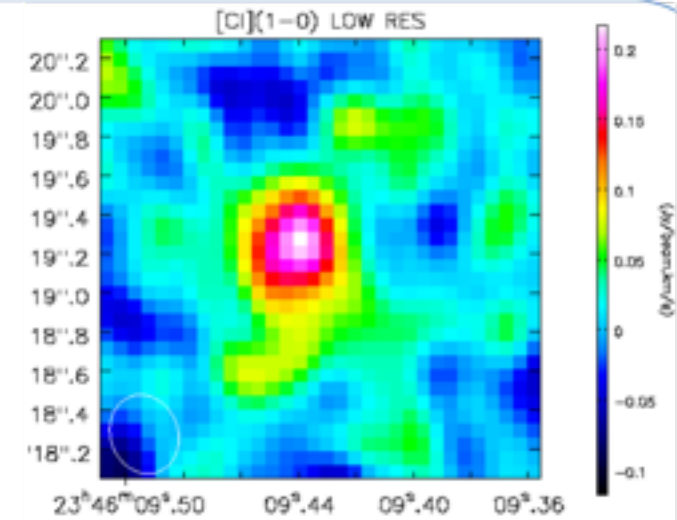
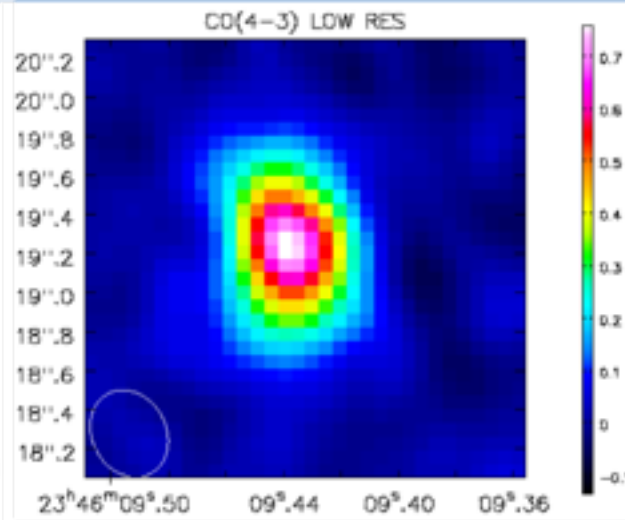
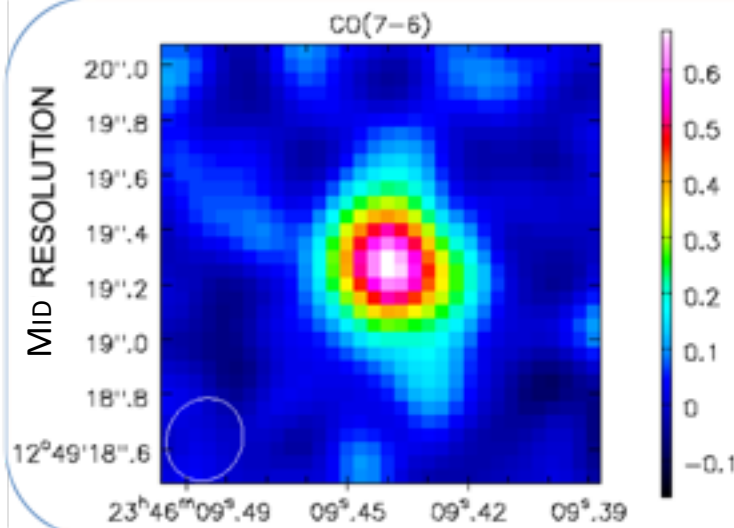
- Full ALMA



HIGH RESOLUTION



MID RESOLUTION

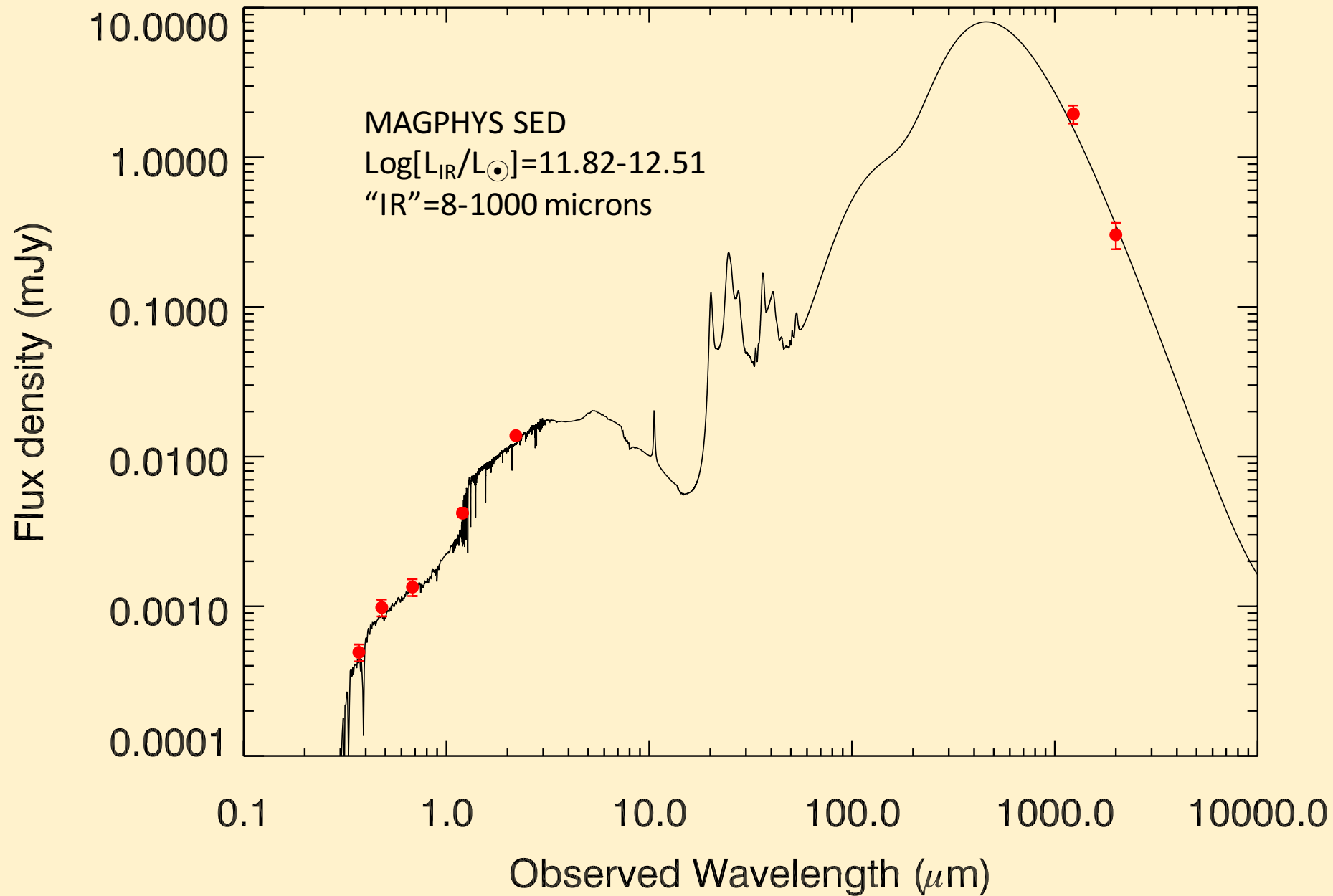


# Summary

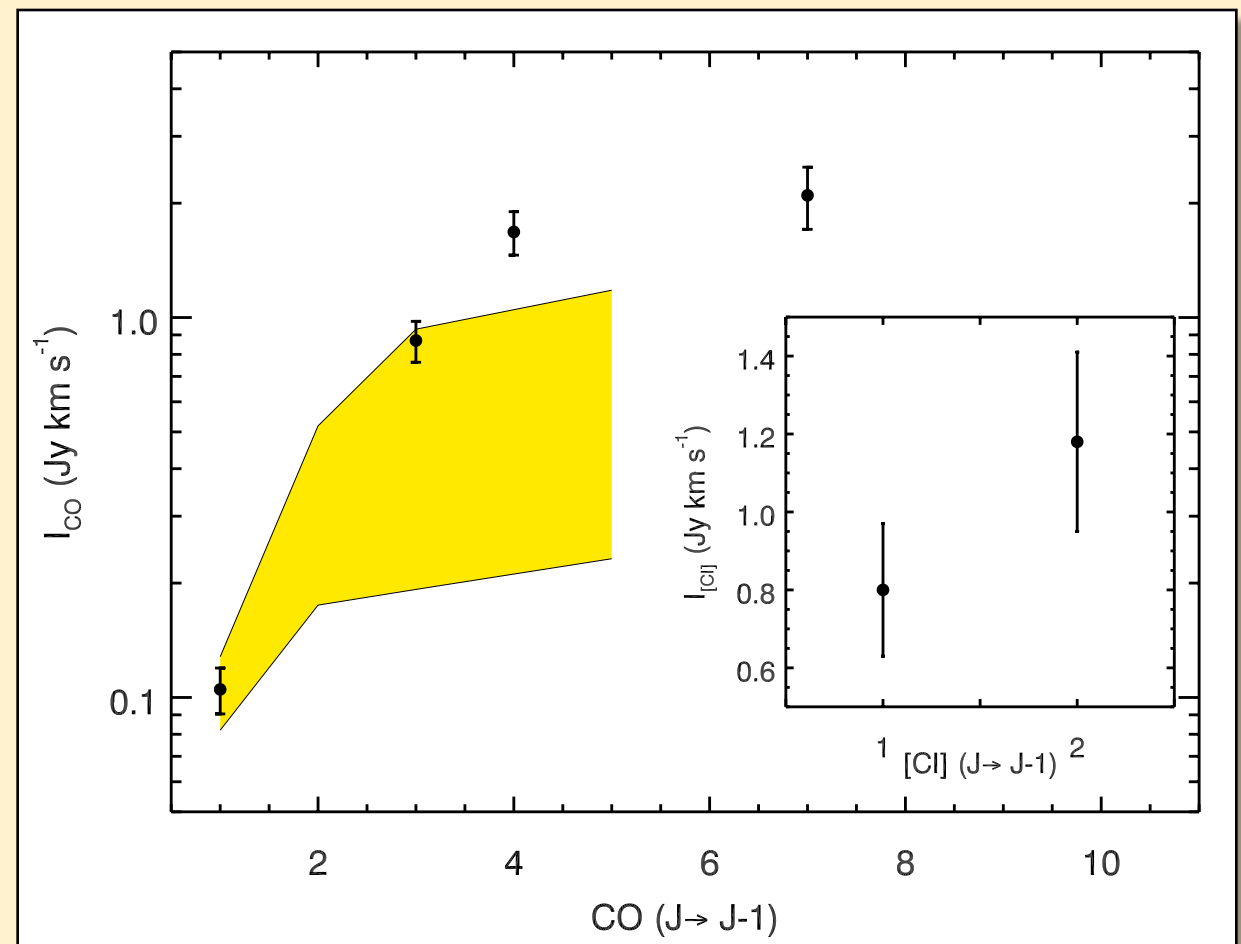
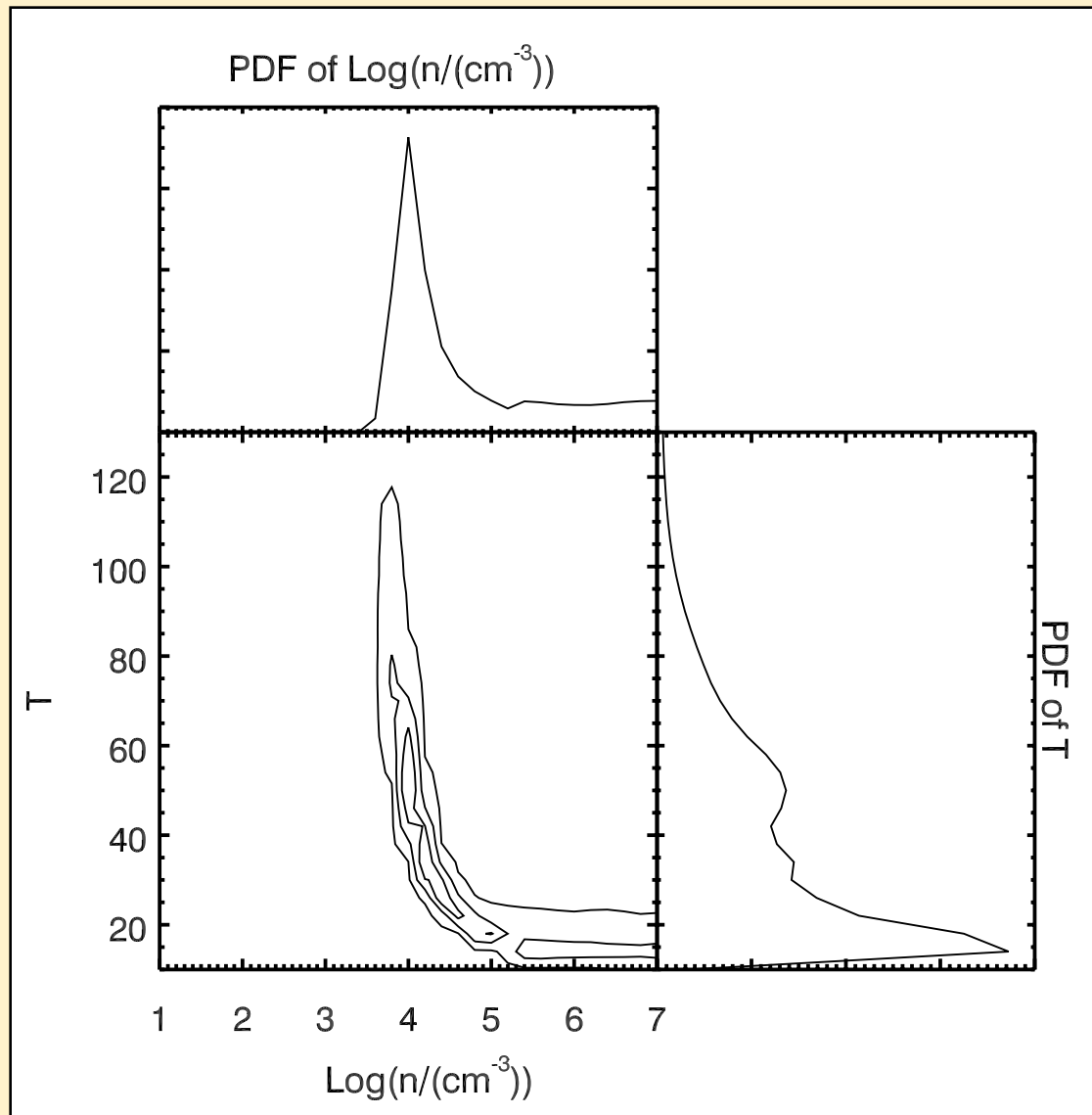
- rare example of  $z \sim 2$  main sequence galaxy with multiple submm. lines
- Consistent gas estimates:  $M_{\text{gas}} \sim 10^{11} M_{\odot}$ 
  - $\alpha_{\text{CO}} \sim 4.36 \text{ (K km/s pc}^2\text{)}^{-1}$
- Large  $\text{CO}(7-6)/L_{\text{IR}}$ 
  - Shocks?
- BX610 is forming stars vigorously, less intense than cSFG
- High res analysis will investigate gas distributions, nature of shocks
- Care should be taken investigating clumps

# References

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# Gas modeling: Large Velocity Gradient





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