SEARCHING FOR CONVERGING FLOWS ONTO A MOLECULAR CLOUD

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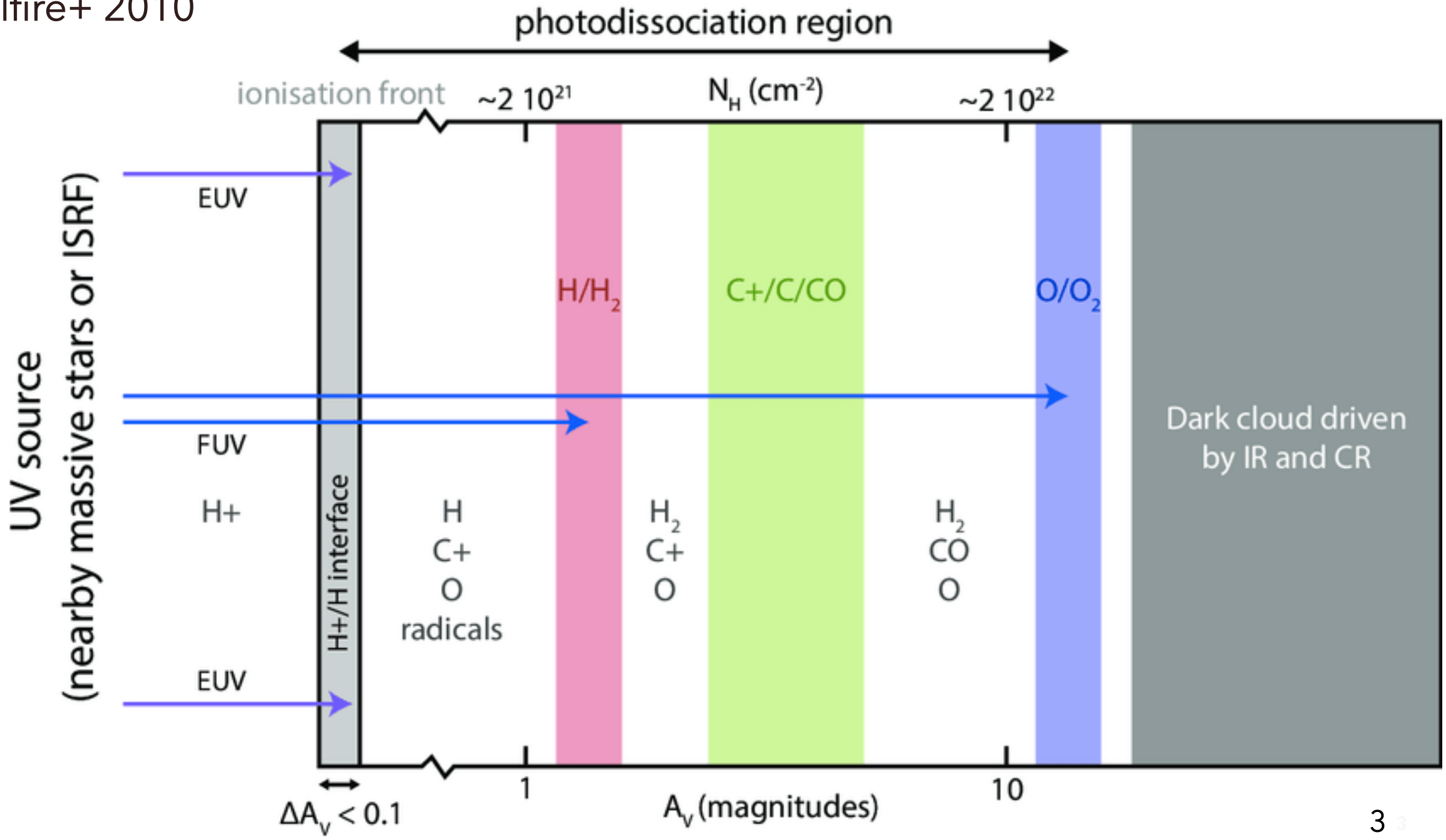
SPITZER SPACE TELESCOPE

Serpens South

NASA WEBB SPACE TELESCOPE

NGC 3324

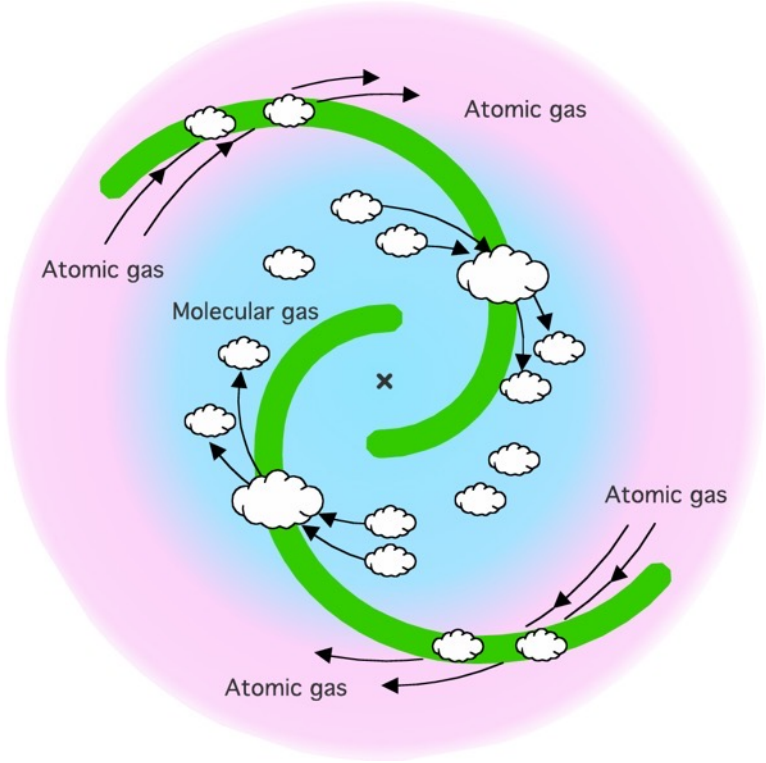
Wolfire+ 2010



ASSEMBLY OF GMCS

Top-Down Cloud Assembly

- H_2 emerges from instabilities in compressed atomic gas layers
- Shocks from spiral density waves, SNR, converging flows
- Cloud lifetimes = H_2 lifetimes ≤ arm crossing time ~ 10-50 Myr



Koda+ 2016

Bottom-Up Assembly

- GMCs build up from ***existing*** small H_2 clouds in spiral arms
- GMCs disassemble into smaller H_2 clouds upon exiting spiral potential that transit to next arm
- H_2 lifetimes are much longer than cloud lifetimes (> 10^8 years)

Monthly Notices
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Mon. Not. R. Astron. Soc. **424,** 2599–2613 (2012) doi:10.1111/j.1365-2966.2012.21259.x

How long does it take to form a molecular cloud?

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[2] *Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St Andrews, The North Haugh, St Andrews, Fife KY16 9SS*

Converging flow simulation using Gadget2 SPH code

- Follow chemistry evolution of H,C in simplified network
- M=4x10^4 M_{sun}, Volume=111 pc x 36 pc x 36 pc
- vflow=6.8 (slow),13.6 (fast) km/s

Monthly Notices
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MNRAS **486,** 4622–4637 (2019)
Advance Access publication 2019 April 20

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Tracing the formation of molecular clouds via [C II], [C I], and CO emission

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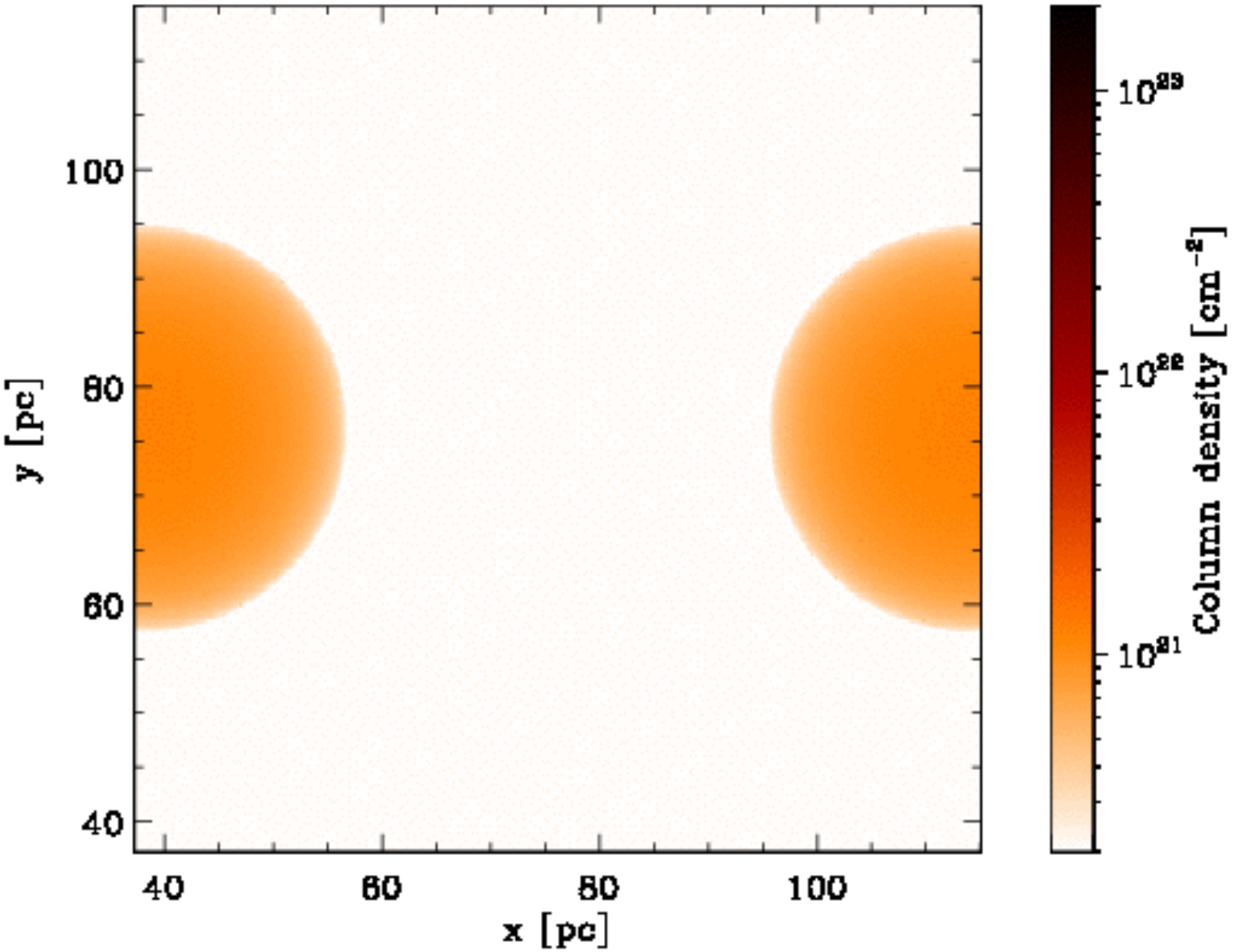
Converging flow simulation using AREPO

- Collision velocities: +/- 3.5 km/s
- Varied G_O: 1.7, 5.1, 17 Habings; CRIR: $3x10^{-17}$, $9x10^{-17}$, $3x10^{-16}$ sec^{-1}
- Simulation halted once sink particles appear
- Radiative transfer/excitation to derive [CII], [CI], CO intensities and profiles

Converging Flow --- Clark+ 2019

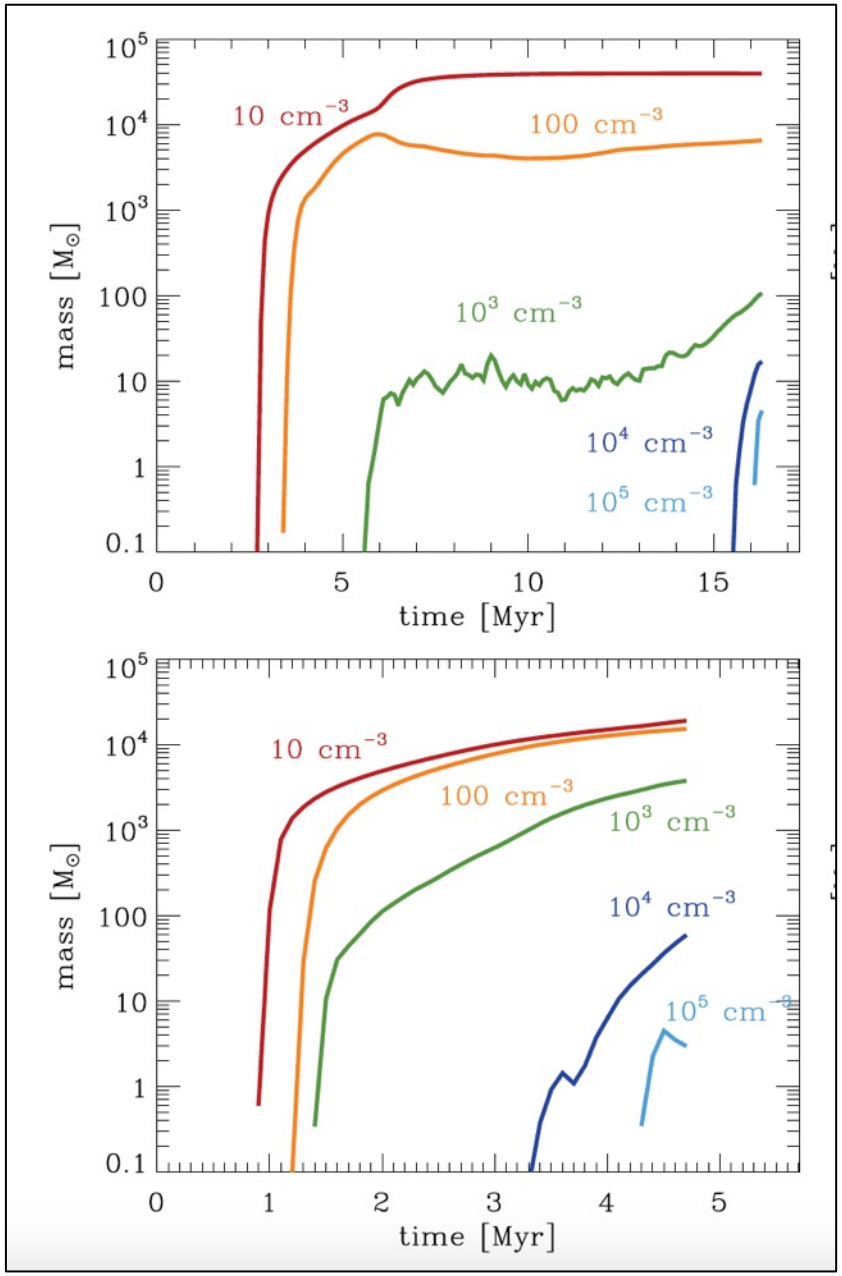


Clark+ 2012

vflow=+/-3.4 km/s

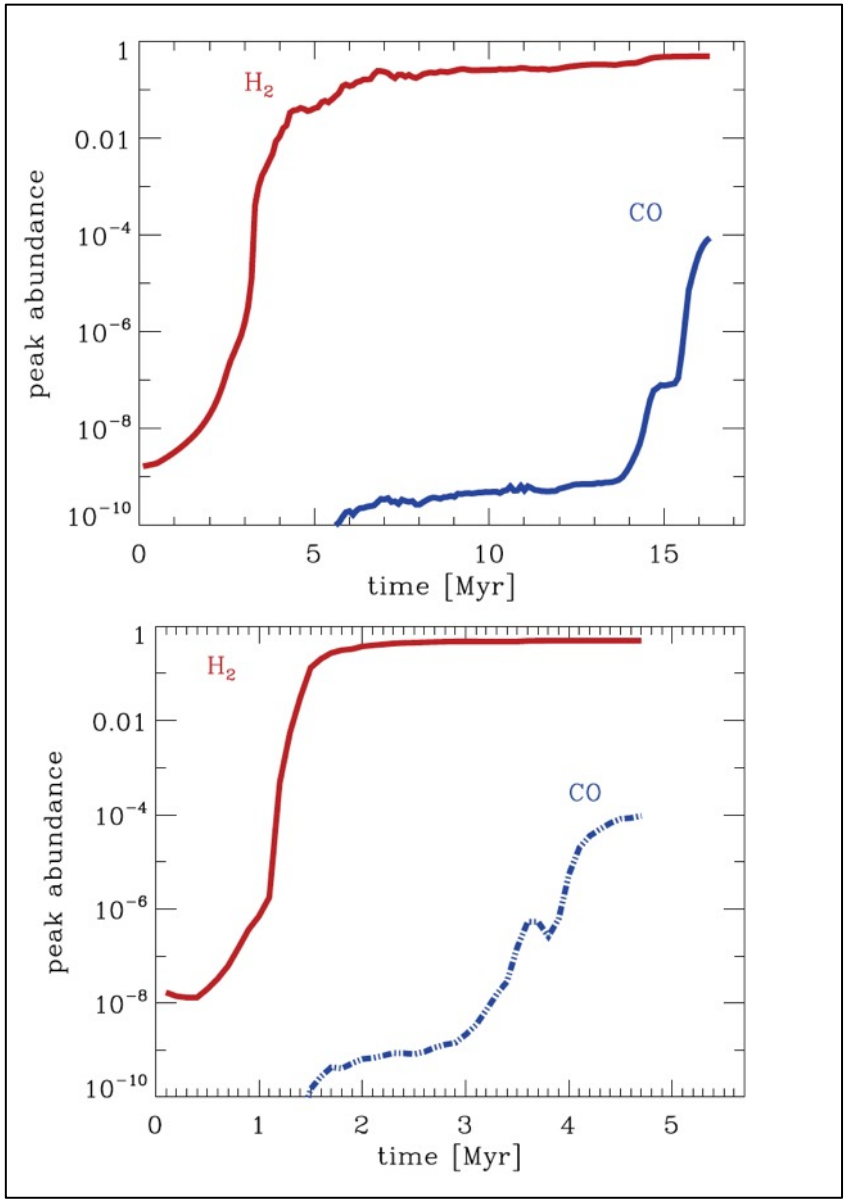
vflow=+/-6.8 km/s

M (n > n')



vflow=+/-3.4 km/s

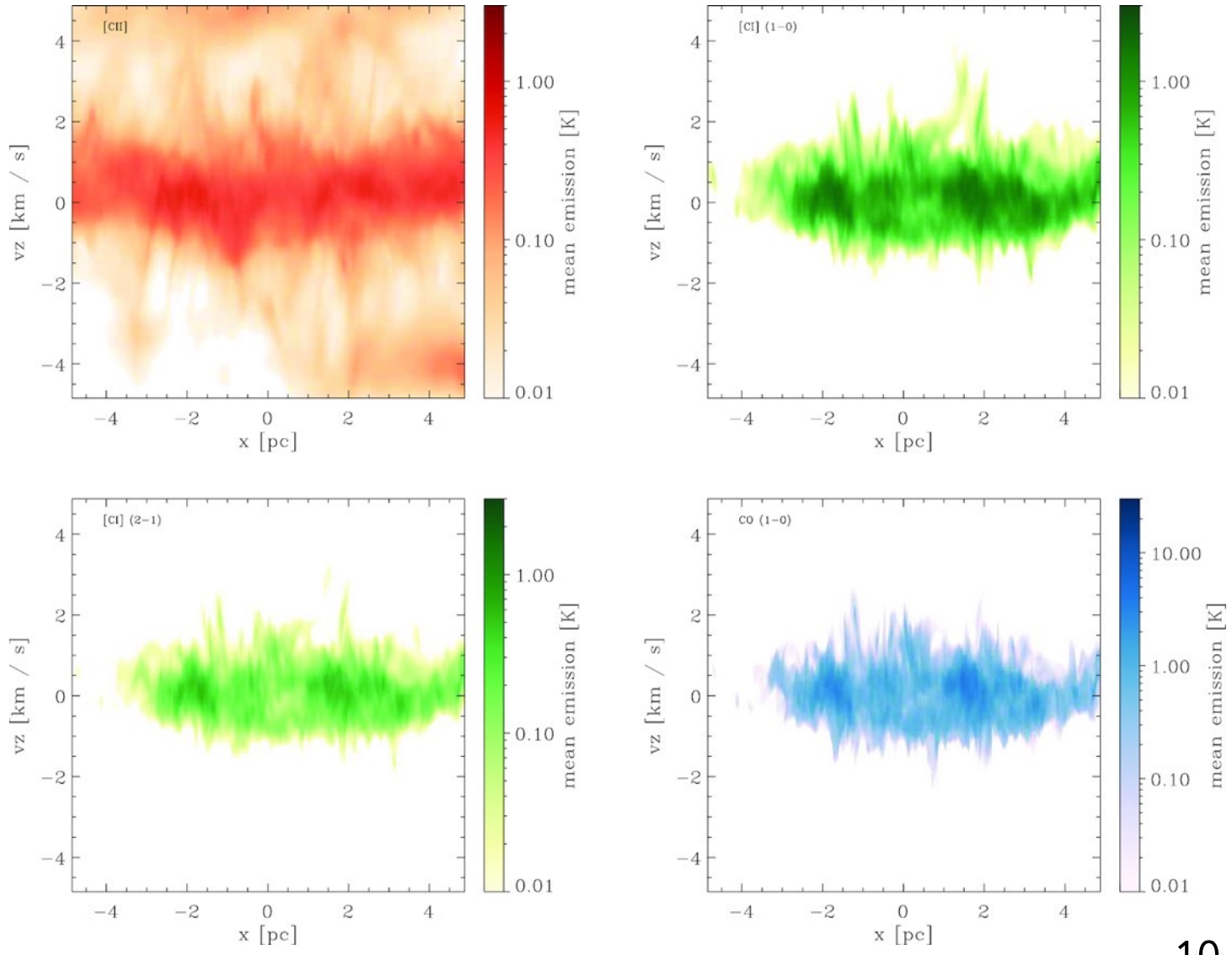
vflow=+/-6.8 km/s



Kinematic Signatures to converging flows

[CII]:

- Most emission originates from atomic gas (little dark CO) with T<100 K
- Brightest emission aligned with [CI], CO
- Faint striation features connect bright emission at vz=0 to the faint bridges at +/- 4 km/s.



upGREAT instrument
U. Cologne/MPIfR

LFA:

- 14 pixels (7x2 polarizations)
- Freq: 1.835-2.007 THz
- FFT Spectrometers:
  BW=4 GHz, 244 kHz resolution
- 14.1” beam at 1.9 THz

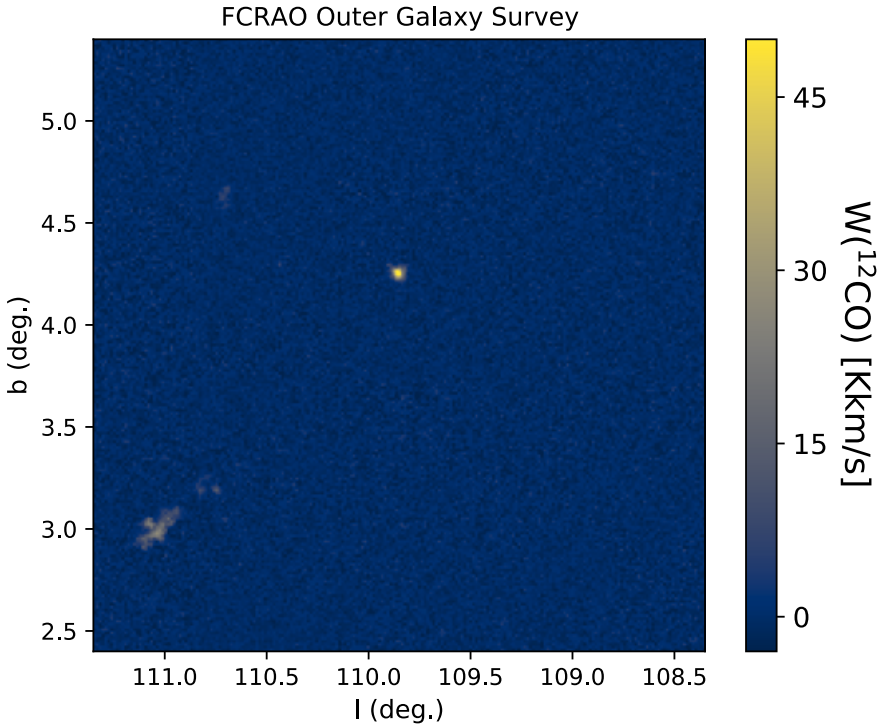
Target: BKP 7323

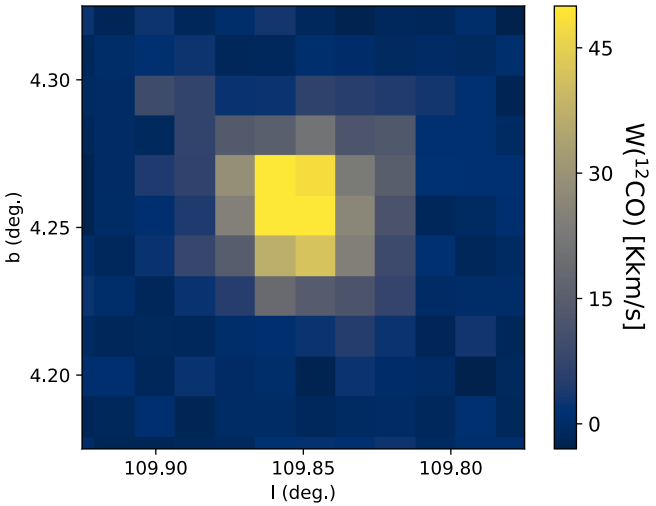
Brunt+ 2003 catalog of clouds in the FCRAO Outer Galaxy Survey

- Distance=3.23 kpc
- 1100 Msun, R=3 pc
- star formation activity (Ragan+ 2012, Beuther+2021) ISOSS J22478+6357

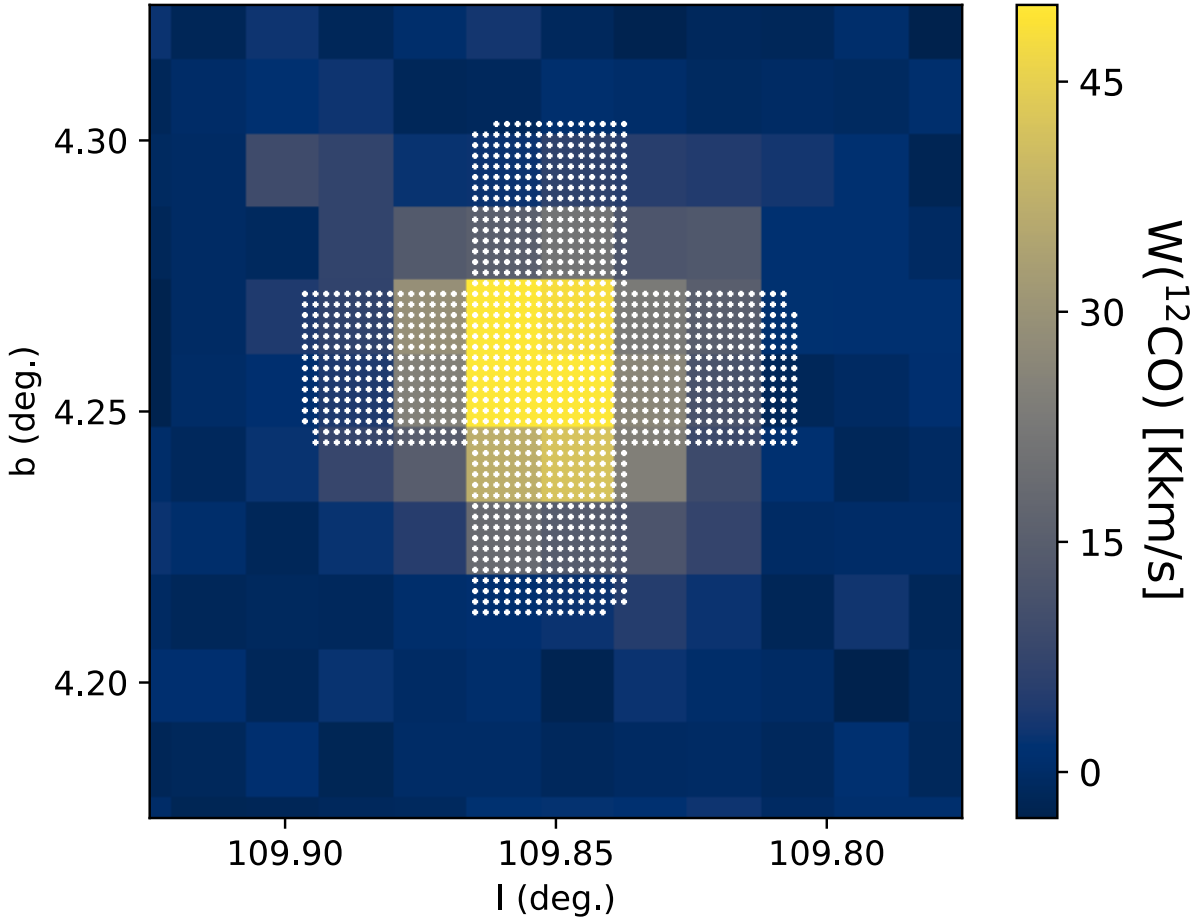
Data:

- SOFIA/upGREAT (Cycle 8)
- FCRAO Outer Galaxy Survey (^{12}CO)
- DRAO/CGPS (HI 21cm)

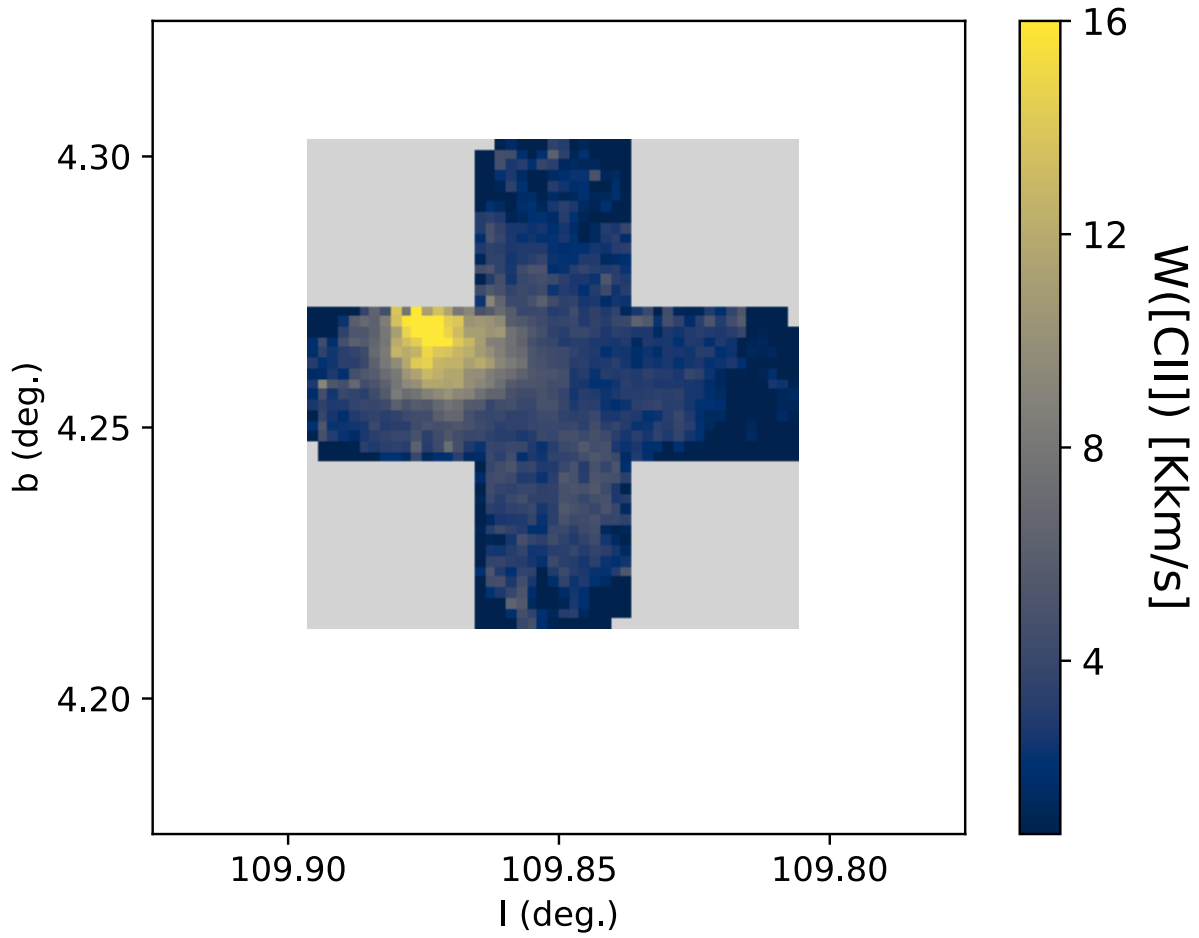




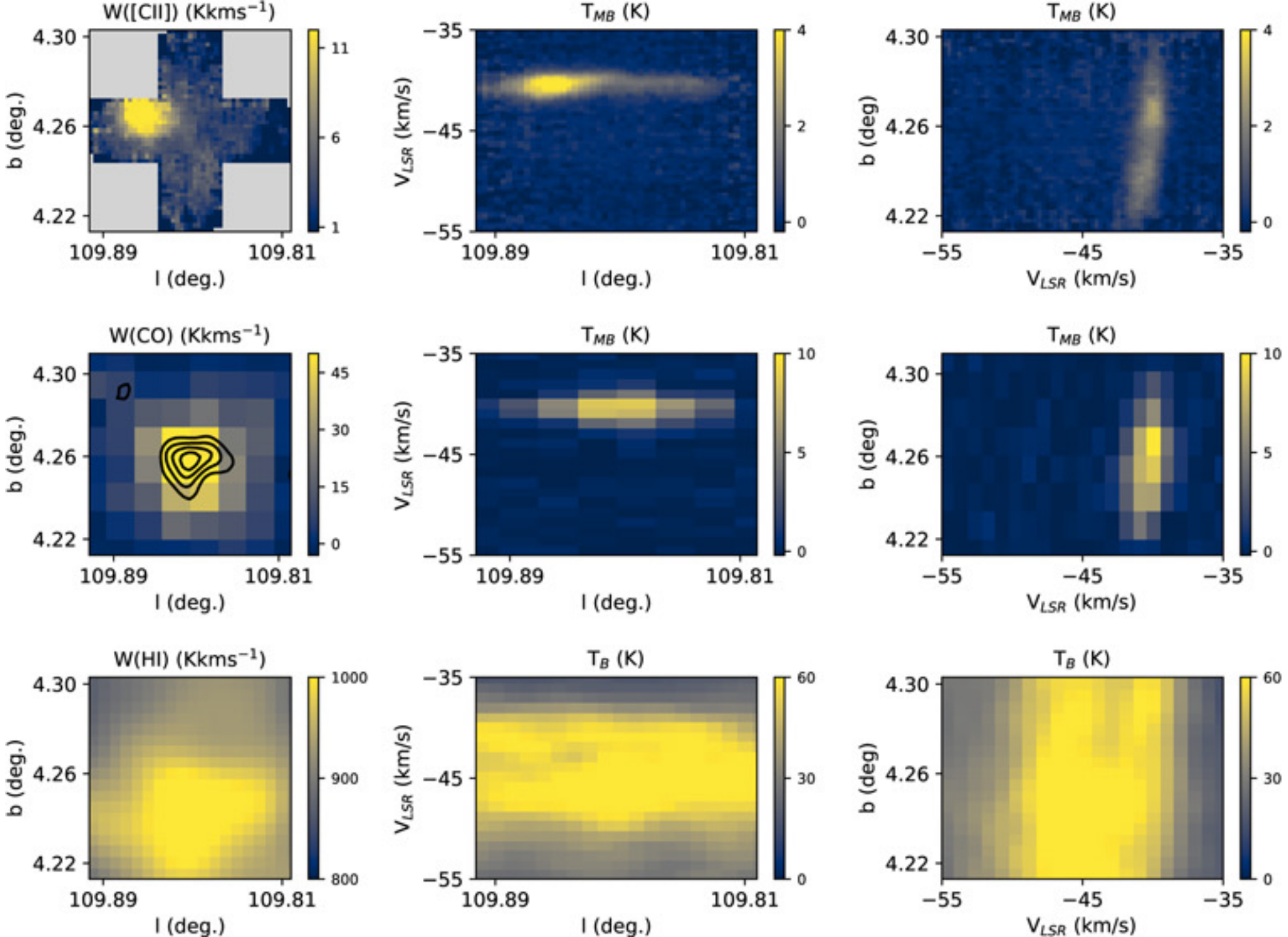
[CII] coverage on CO map after regridding



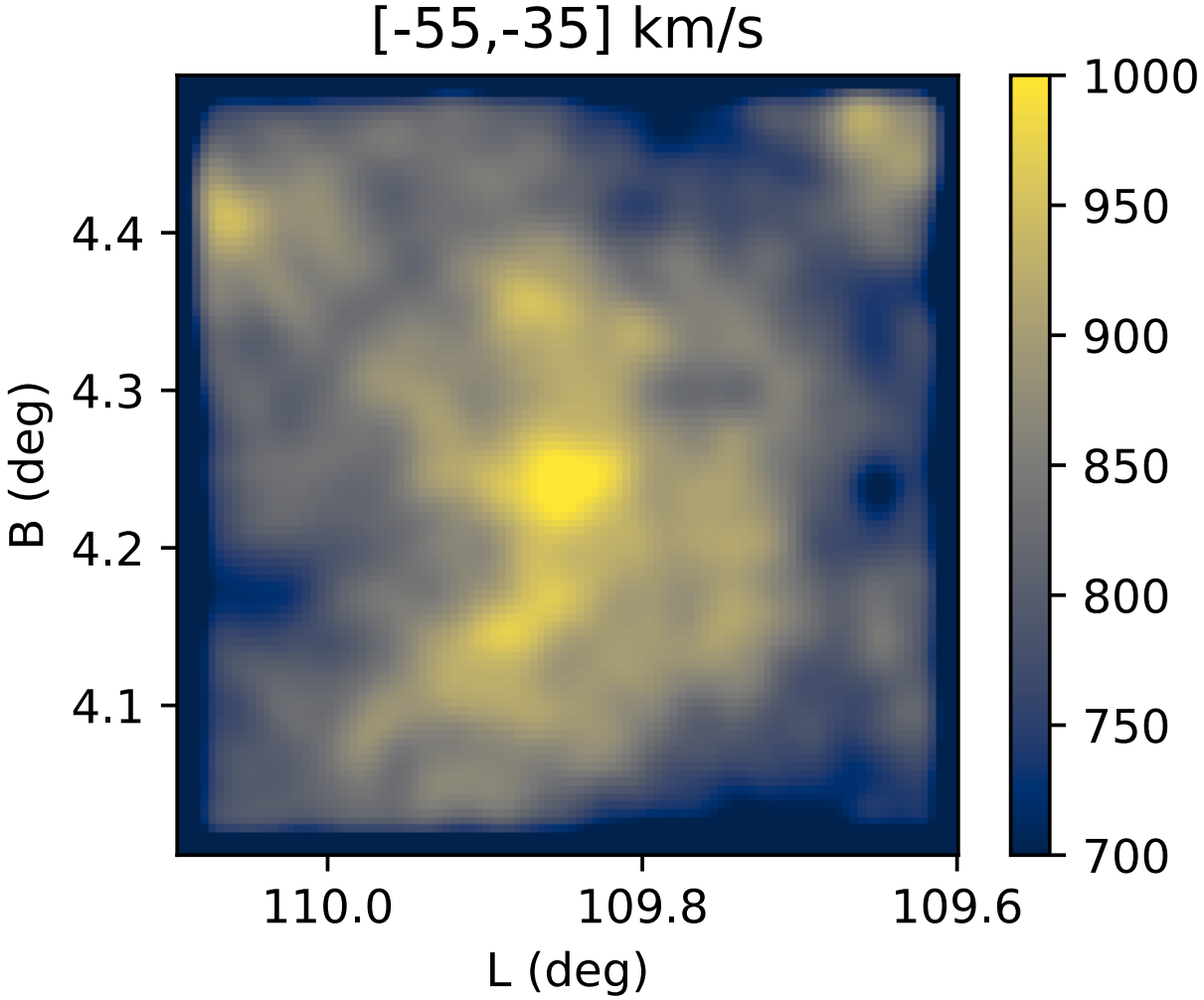
[CII] coverage on CO map after regridding



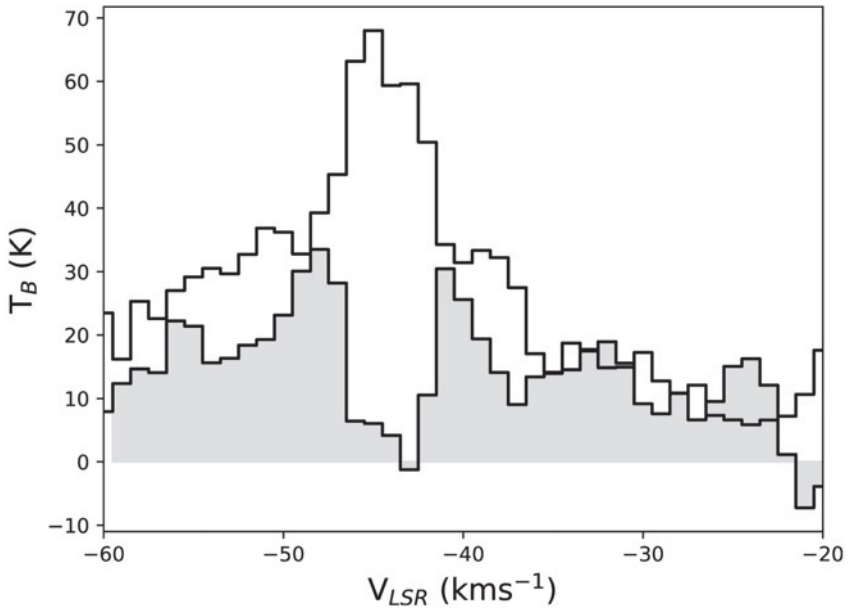
Median rms = 0.22 K in 0.25 km/s wide channels

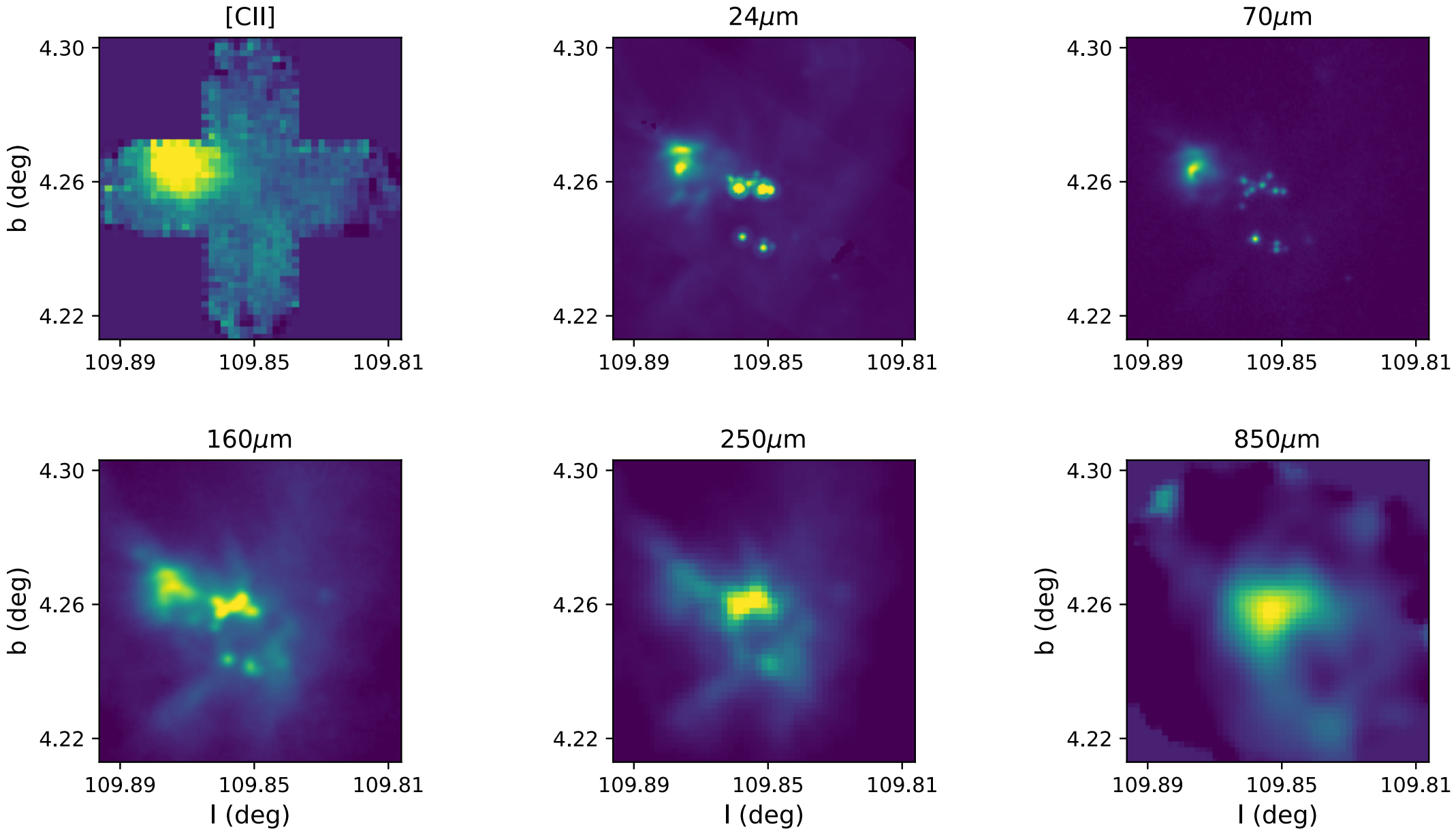

W([CII]) (Kkms^{-1})
T_{MB} (K)
T_{MB} (K)
W(CO) (Kkms^{-1})
T_{MB} (K)
T_{MB} (K)
W(HI) (Kkms^{-1})
T_B (K)
T_B (K)
b (deg.)
b (deg)
l (deg.)
V_{LSR} (km/s)
4.30
4.26
4.22
109.89
109.81
−35
−45
−55
−55
−45
−35
11
6
1
4
2
0
45
30
15
10
5
1000
900
800
60
30

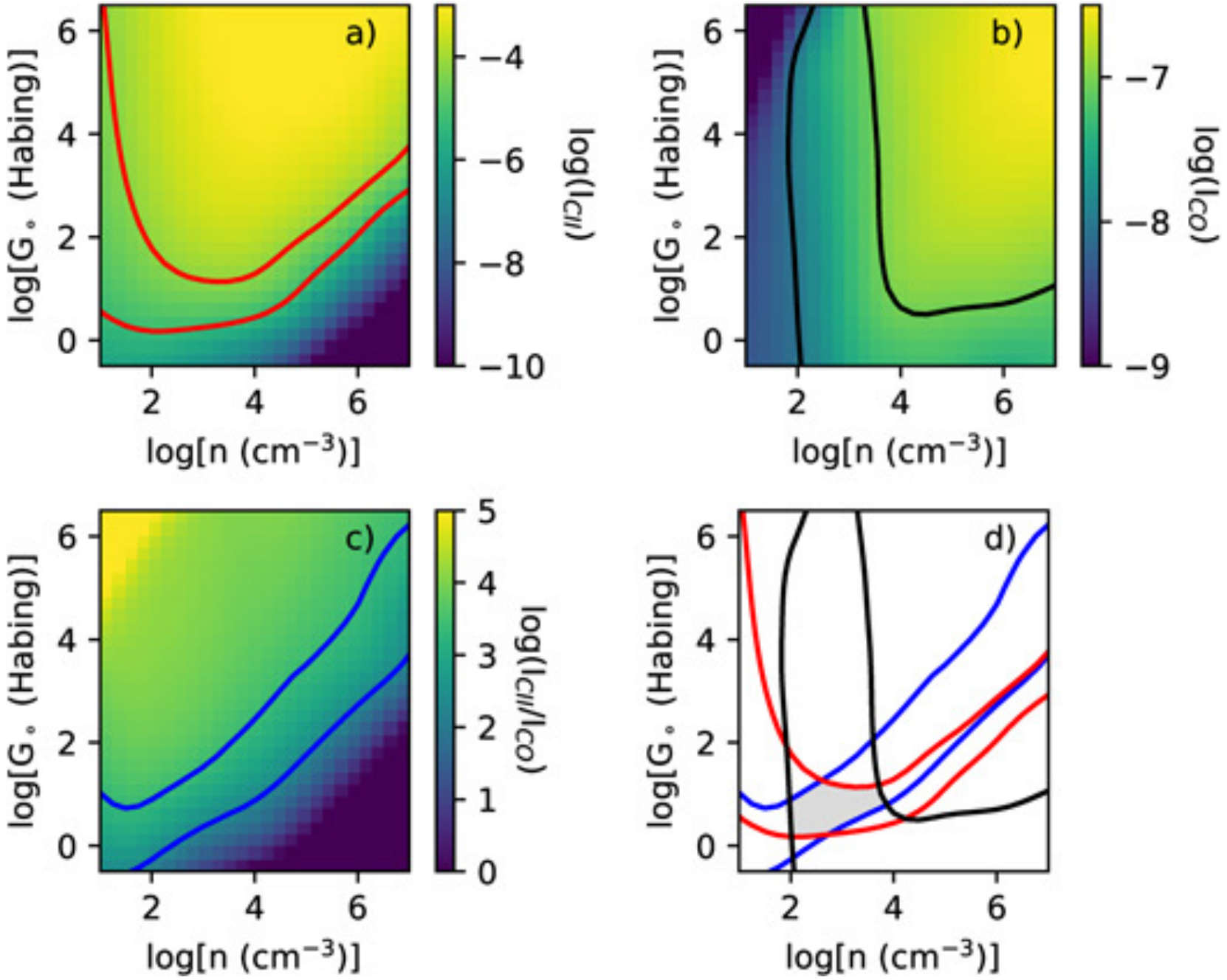
Broader View of HI emission



G109.65+4.24. (shaded area)

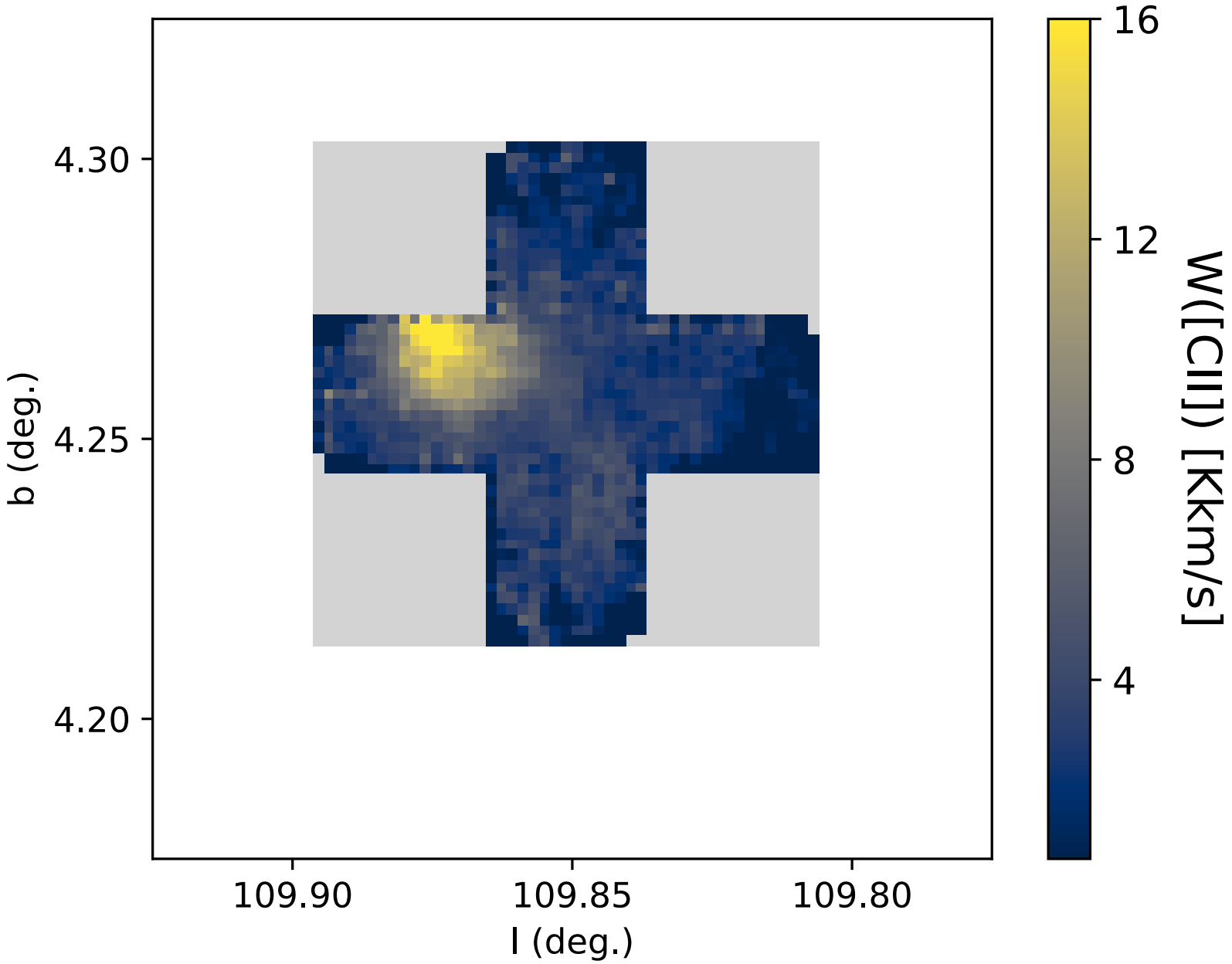



[CII]
24μm
70μm
160μm
250μm
850μm
b (deg)
l (deg)
4.30
4.26
4.22
109.89
109.85
109.81

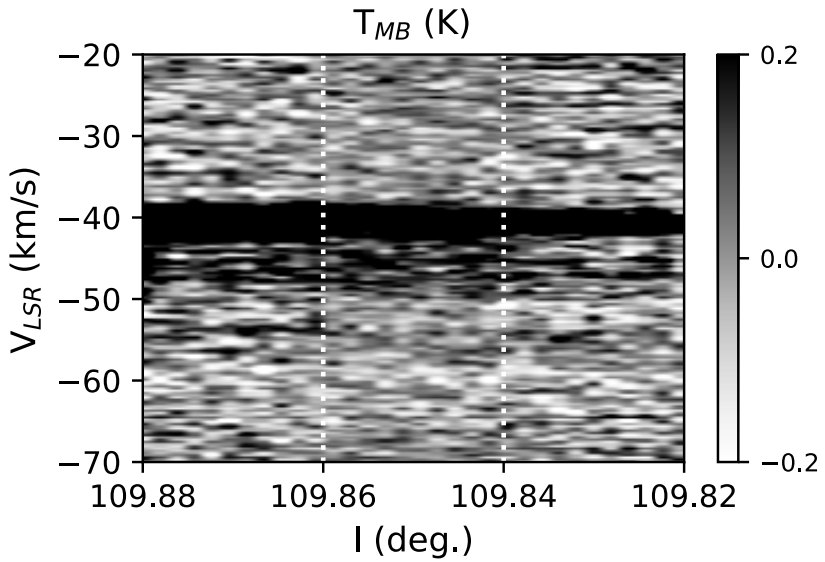


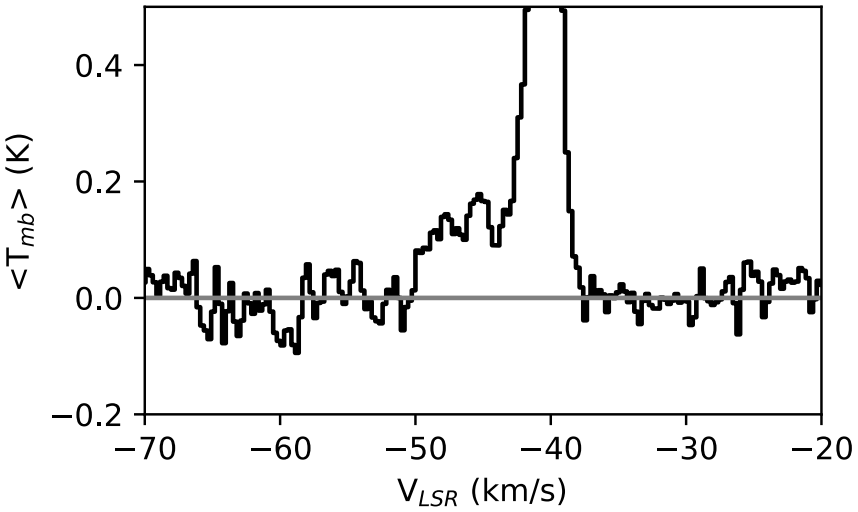
PDR Toolbox
Pound & Wolfire 2023

PDR Conditions:
$2 < \log n < 4$
$1 < G_O < 10$

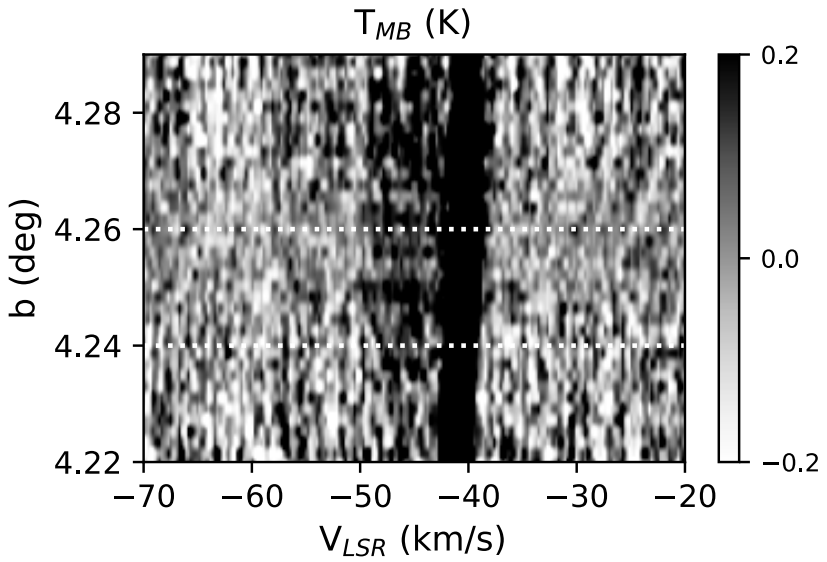

4.30
4.25
4.20
b (deg.)
109.90
109.85
109.80
l (deg.)
16
12
8
4
W([CII]) [Kkm/s]

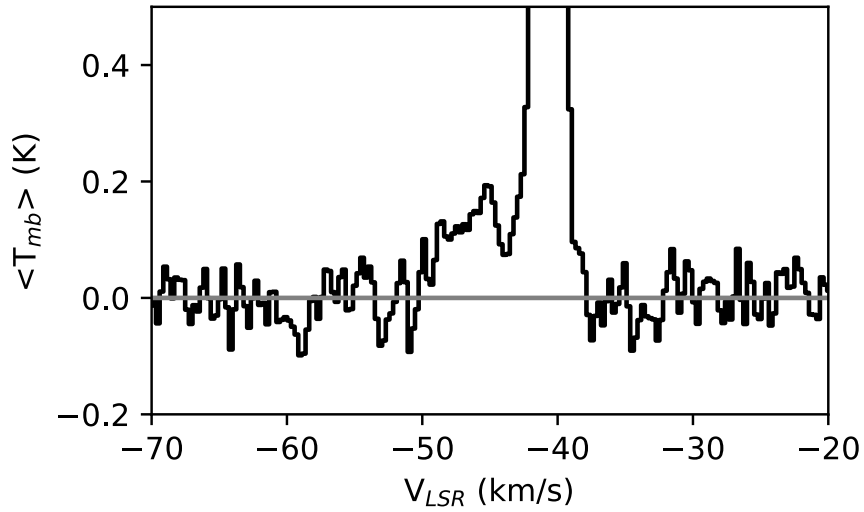
Horizontal Cut

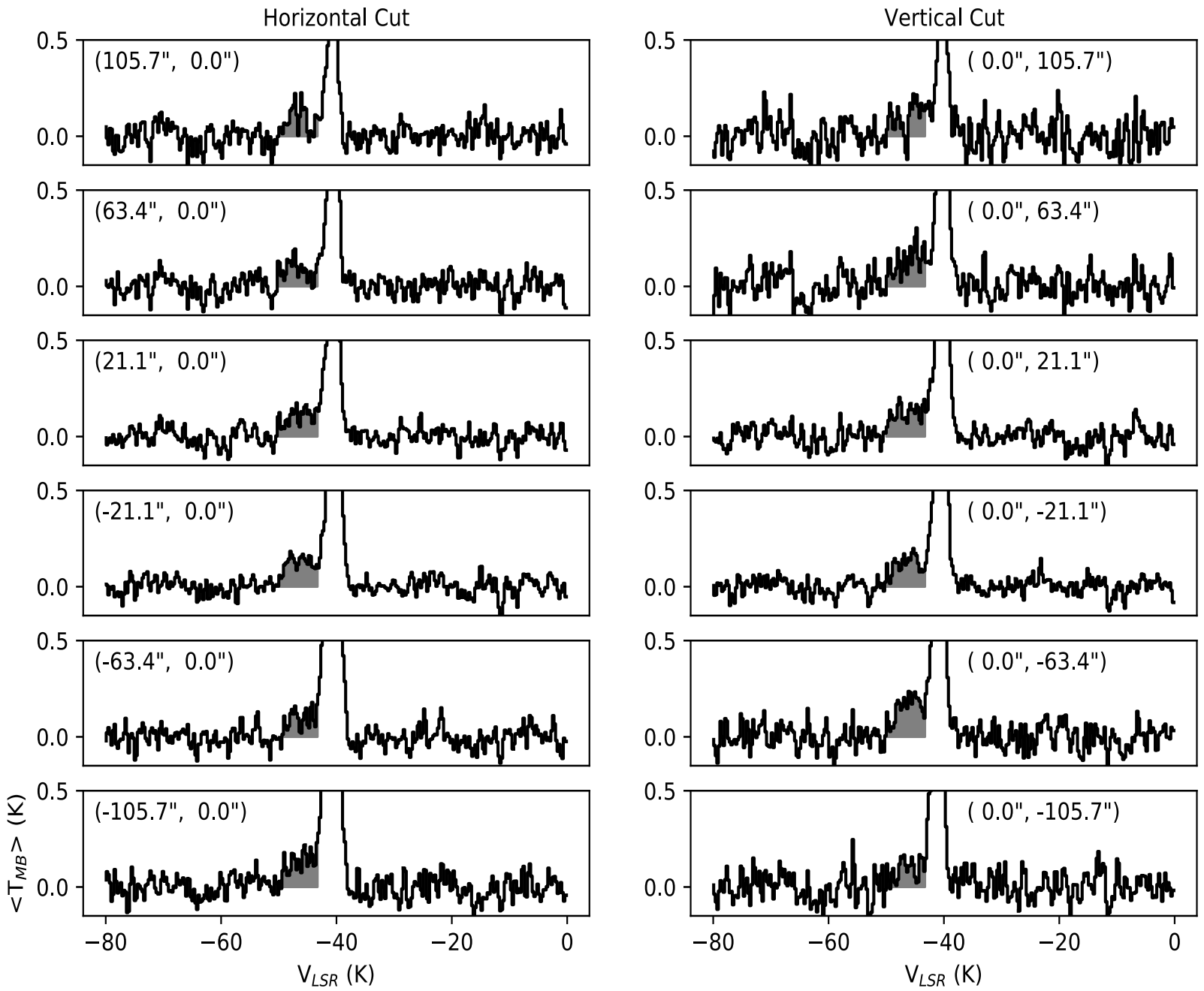




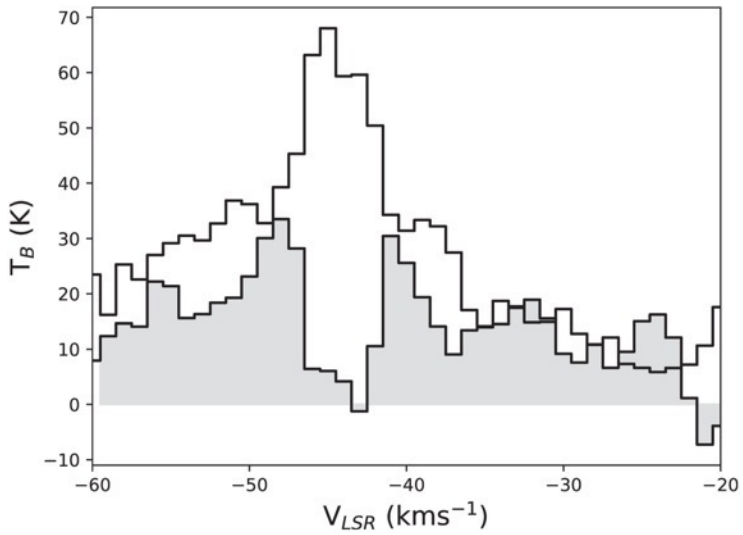
Vertical Cut



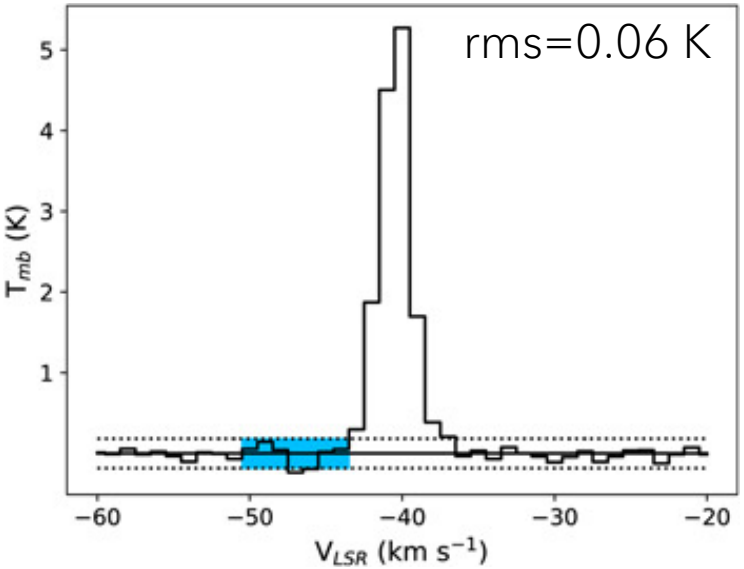


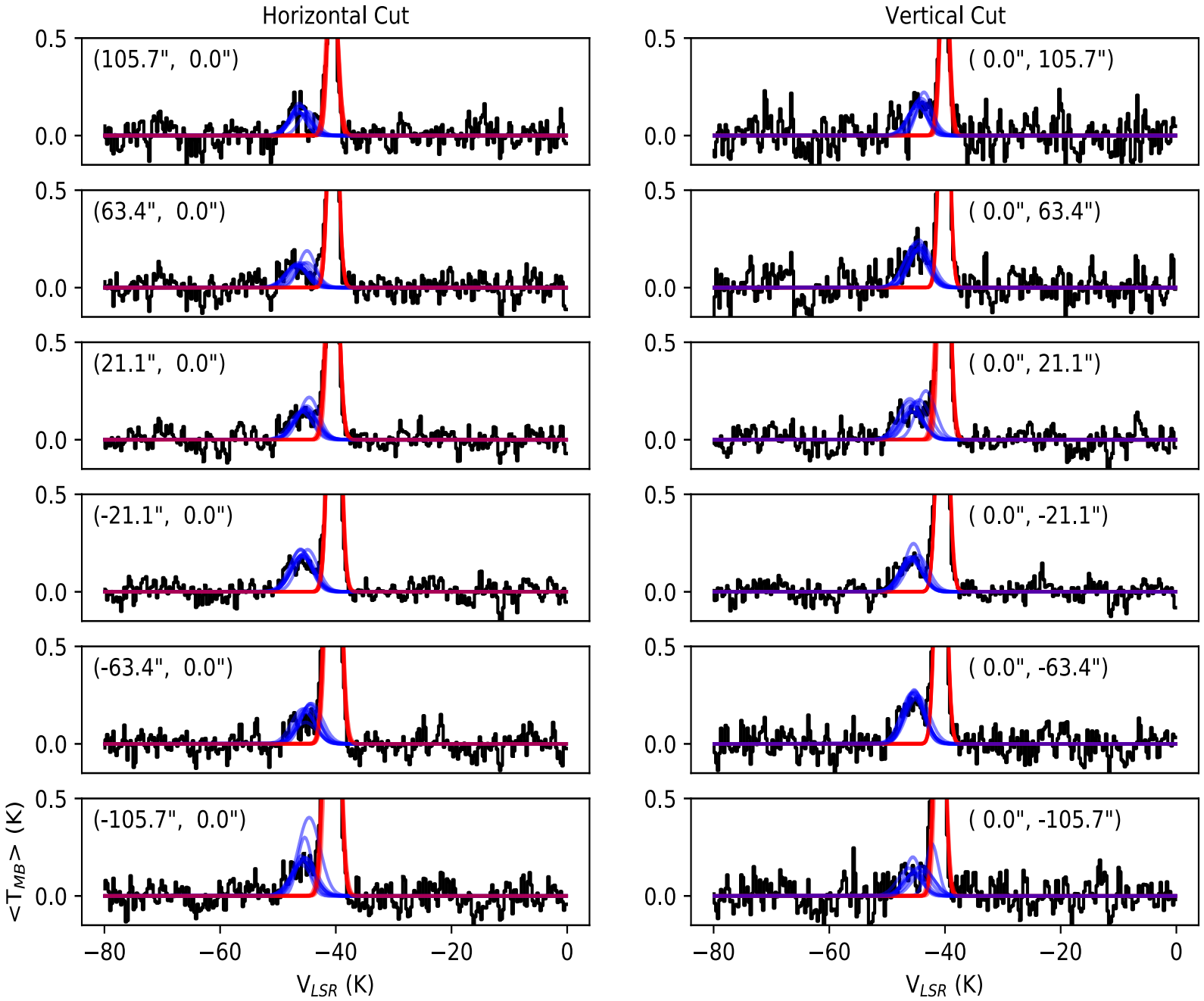


HI 21cm G109.65+4.24



^{12}CO averaged over cloud




Horizontal Cut
Vertical Cut
(105.7", 0.0")
(63.4", 0.0")
(21.1", 0.0")
(-21.1", 0.0")
(-63.4", 0.0")
(-105.7", 0.0")
(0.0", 105.7")
(0.0", 63.4")
(0.0", 21.1")
(0.0", -21.1")
(0.0", -63.4")
(0.0", -105.7")
0.5
0.0
−80
−60
−40
−20
0
V_{LSR} (K)
$<T_{MB}>$ (K)

Volume Density of [CII] wing component

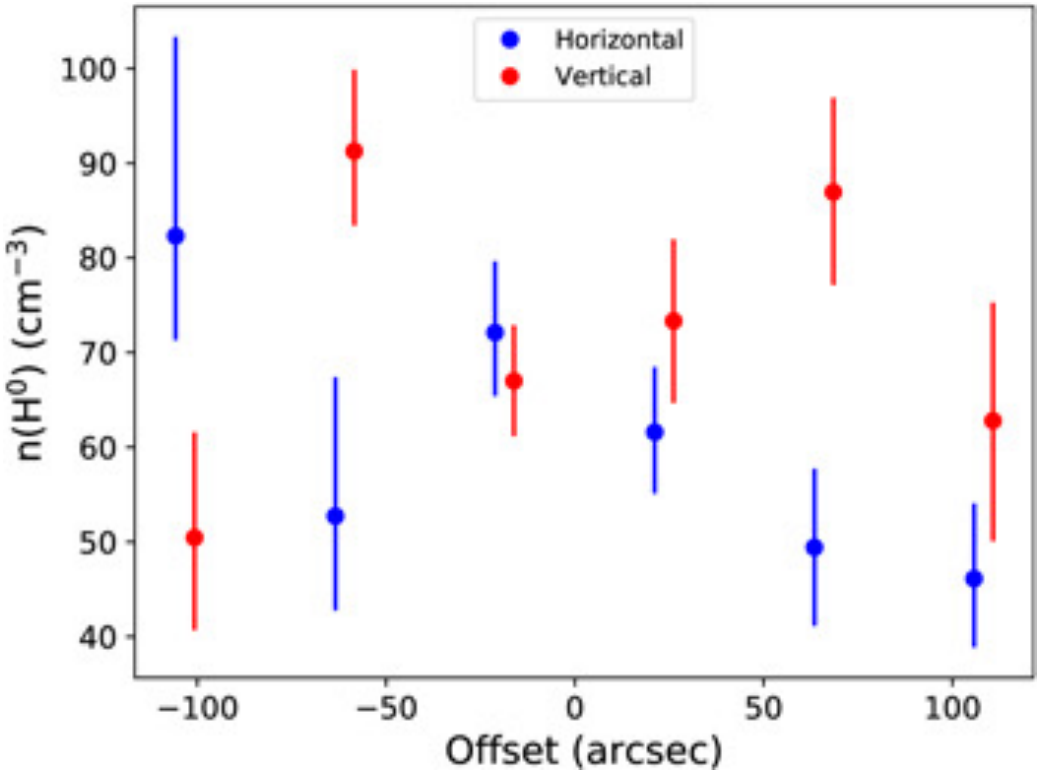
Assumptions:
Optically thin, Collisional excitation with H, Tk=100 K

Langer+ 2010
Goldsmith+ 2018

$$n(H^0) = \frac{3030\,(100/T)^{0.14}}{2\,\exp\left(-\frac{91.2}{T}\right)\left(3.43x10^{-16}\,X-1\right)-1}\ \mathbf{cm^{-3}}$$

Where X=N(C+)/W([CII])

N(C+)=[C/H] 1.823x10^{18} $\int T(HI)dv$
W([CII]= $\int T([CII])dv$



Not the atomic envelope of the CO cloud

CO Cloud Mass = 1100 Msun. Radius = 3 pc

$$\sigma_v = \left(\frac{GM}{5R}\right)^{1/2} = 0.6\ \mathrm{km/s}$$

For dv=4 km/s, gas would separate from the CO cloud within a crossing time = 1.5 Myr

Origin of [CII] wing component

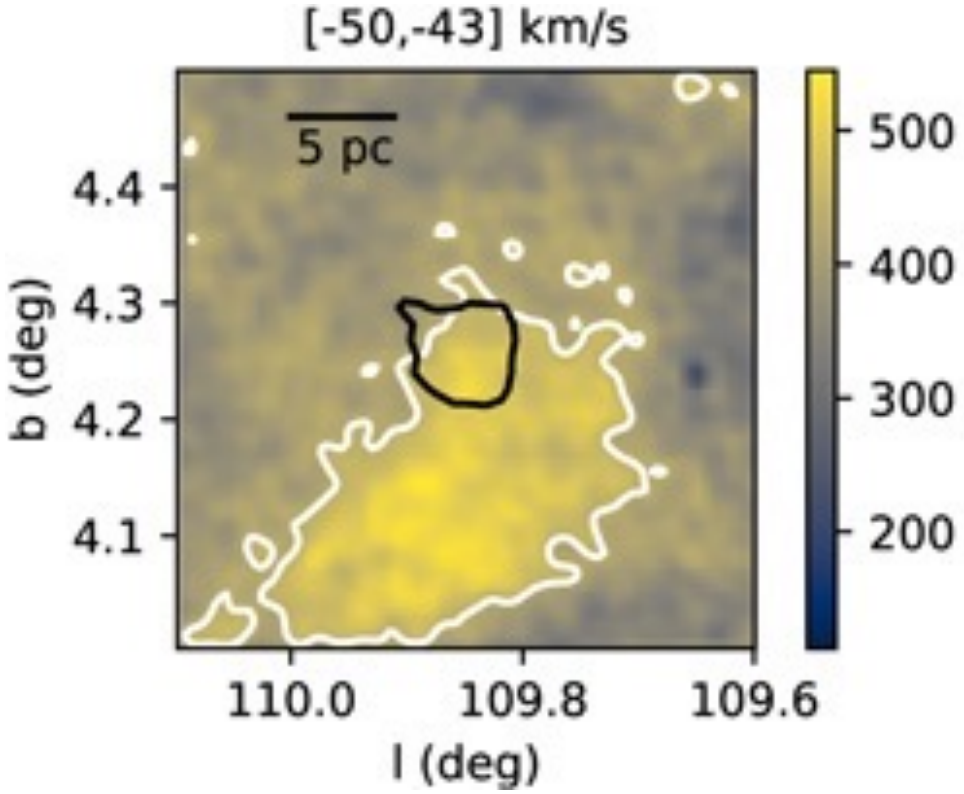
Distinct HI CNM cloud that is **NOT** spatially or kinematically associated with BKP7323

Origin of [CII] wing component

HI CNM layer of gas that is streaming onto BKP 7323 with a flow velocity of ~ 4 km/s

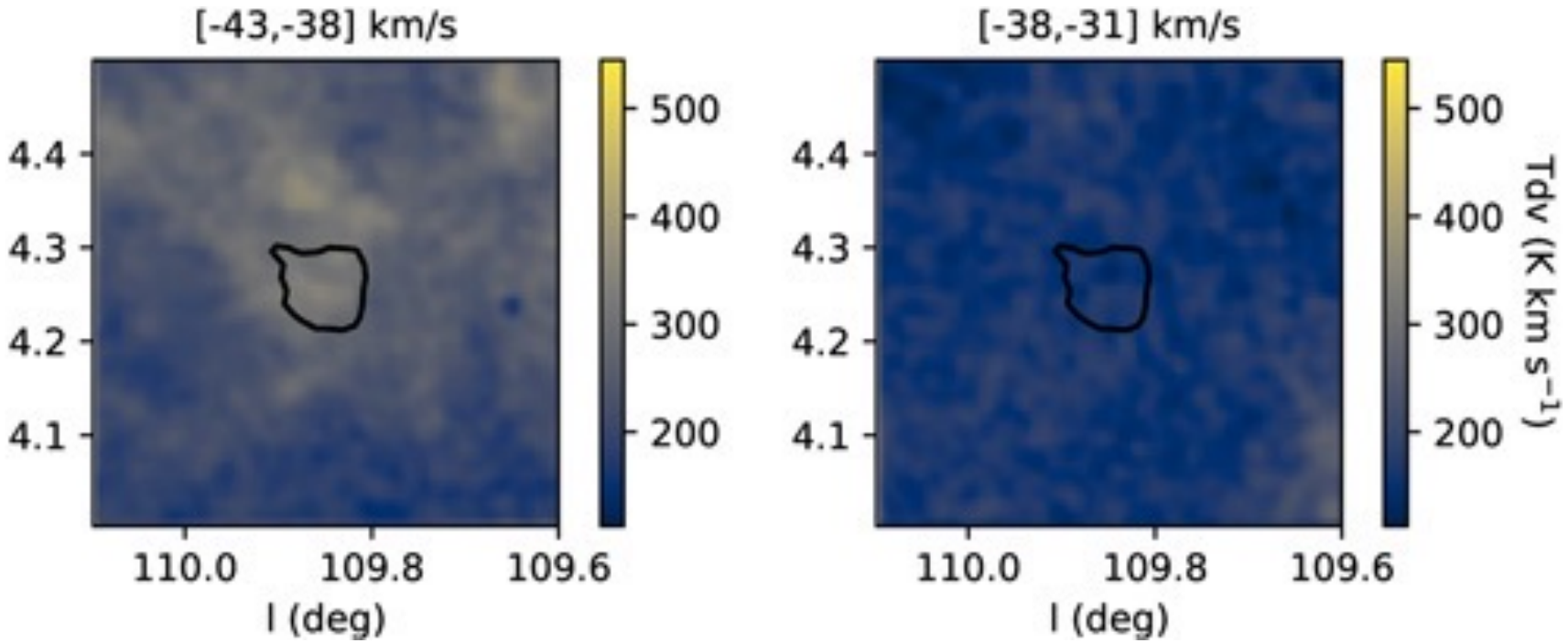
- HI 21cm line shows a strong, localized peak at the central zone of the CO cloud
- 3000 Msun reservoir of atomic gas in this velocity interval
- Mass Flow rate = $\rho v_{flow} L^2$

  $= 3.2 \times 10^{-4}$ *Msun/yr*

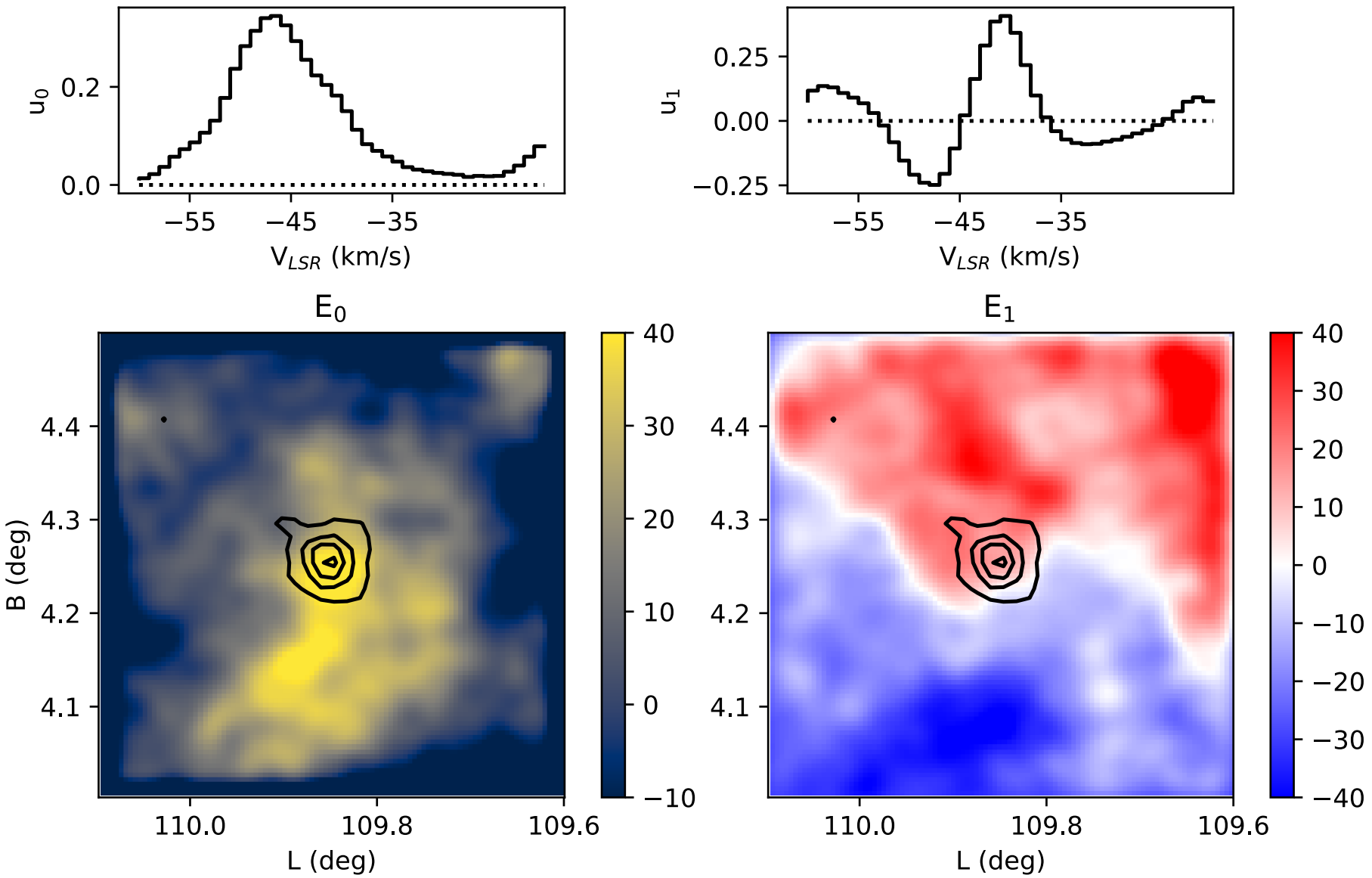


Origin of [CII] wing component

Converging flow HI CNM gas that is onto BKP 7323



PCA of HI 21cm emission



Summary

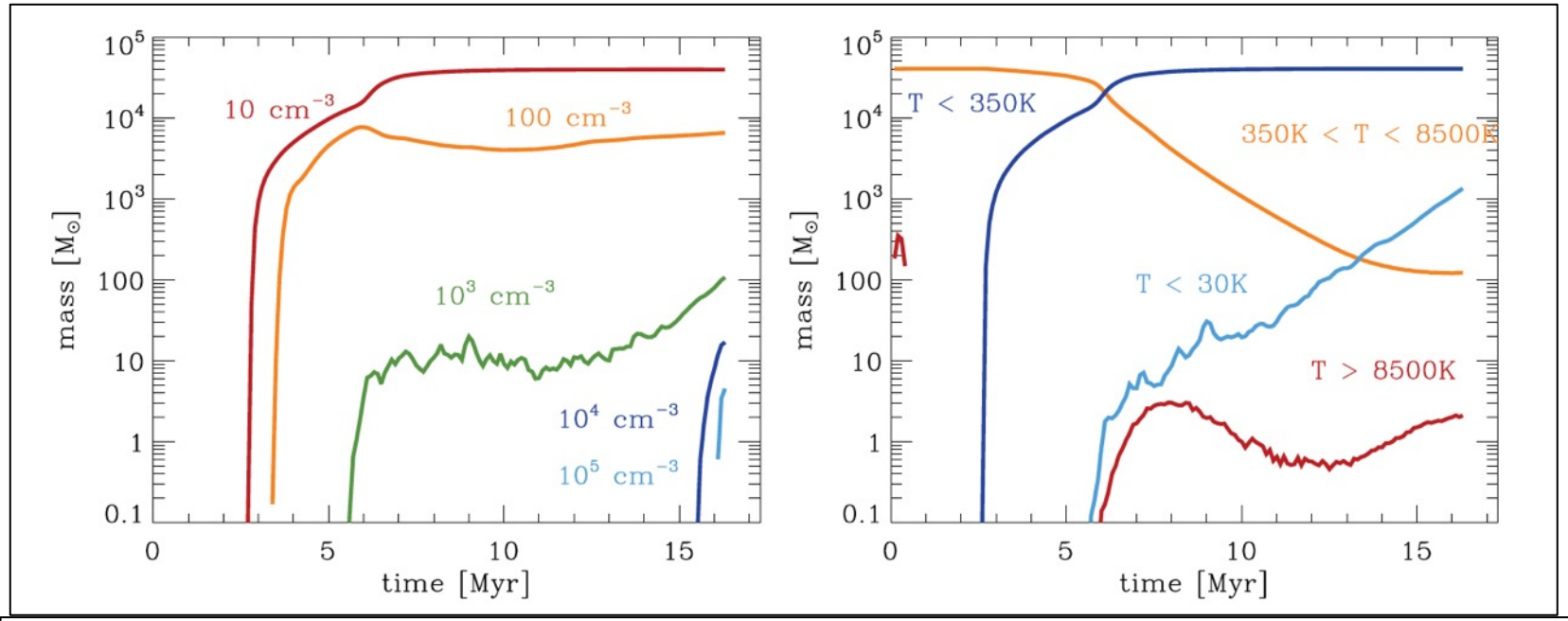
- Limited mapping of [CII] 1.9 GHz line with upGREAT/SOFIA on an isolated cloud. [CII] is complemented by CO and HI 21cm data
- We find bright [CII] emission from BKP 7323 that corresponds to emission from a PDR excited/illuminated by local star formation activity
- Faint [CII] emission in spatially averaged spectra that tracks either CNM or dark CO gas
- The velocity offset of this faint [CII] emission “may be a signature” to a flow of CNM material onto the developing molecular cloud

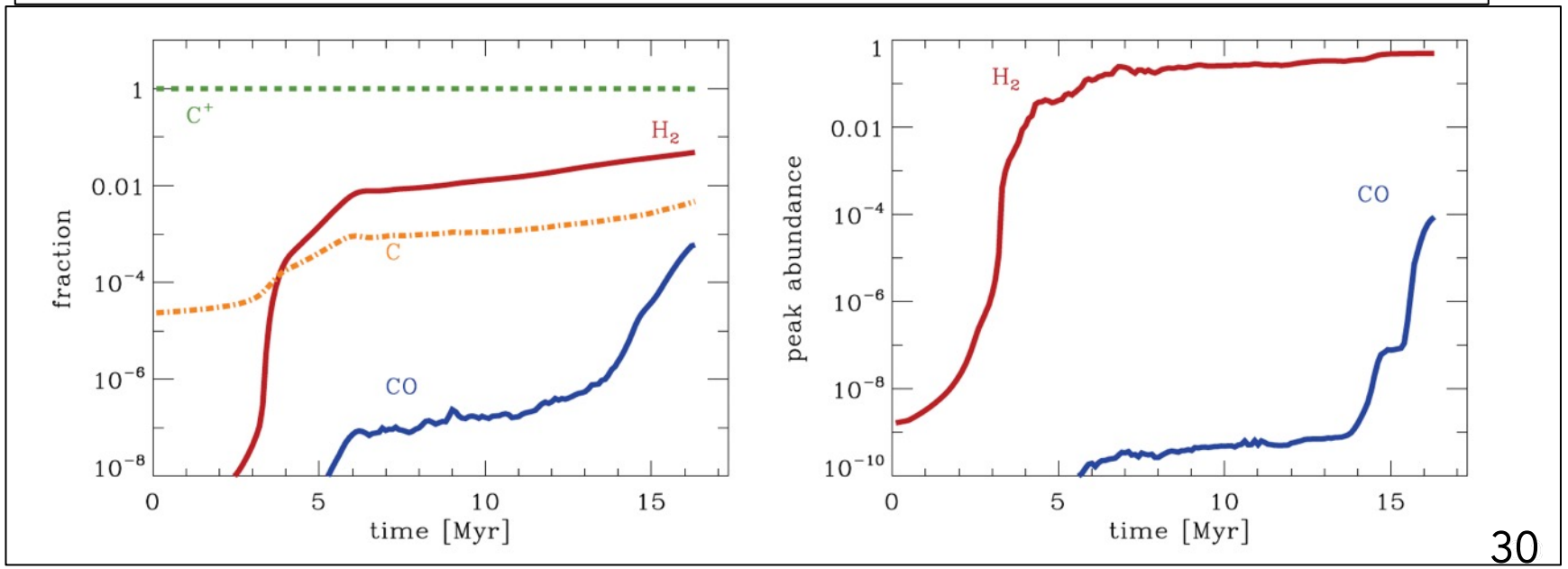
THANK YOU

Clark+ 2012

vflow=+/-3.4 km/s

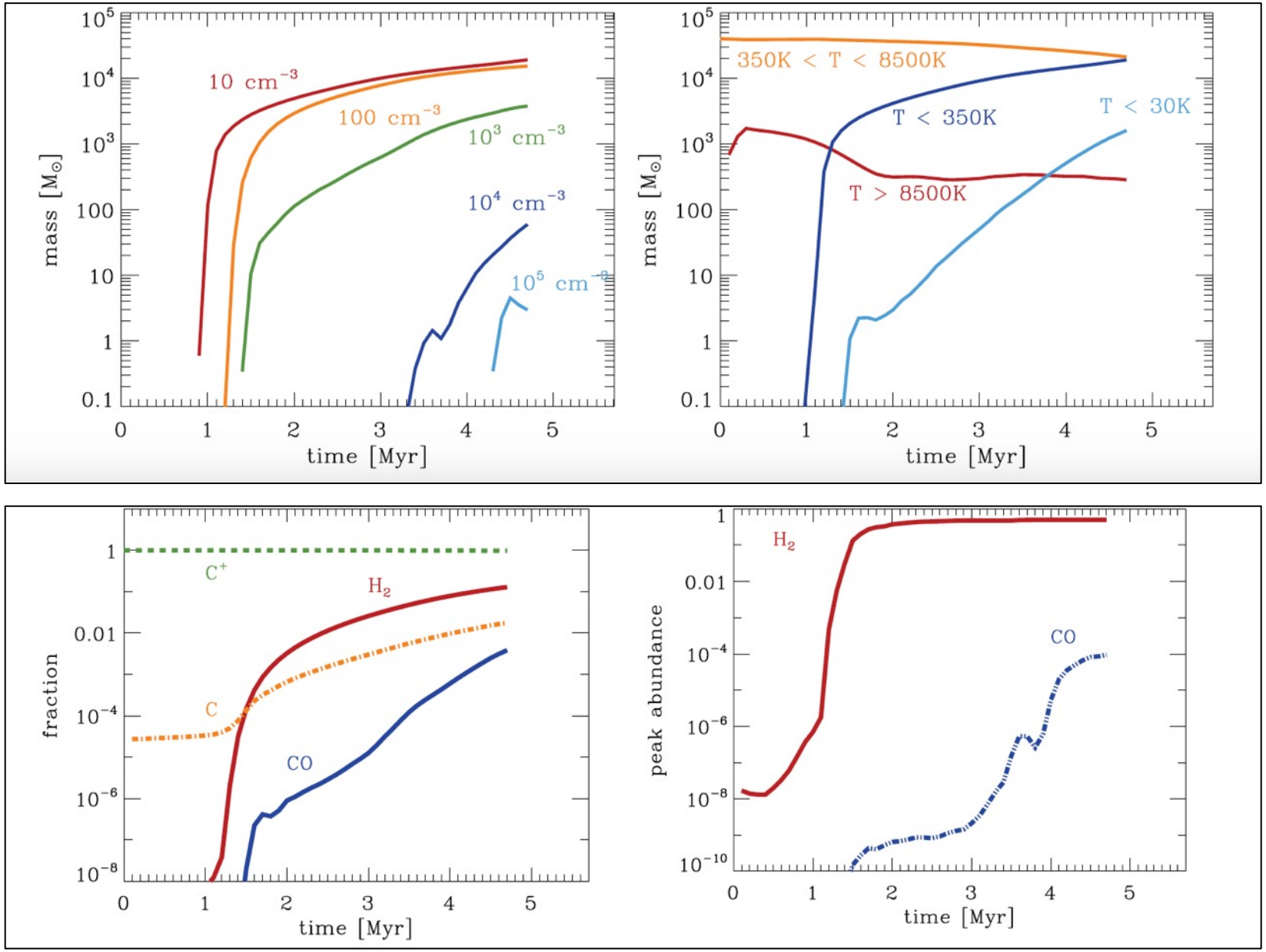
M (n > n') **M(T_1 < T < T_2)**



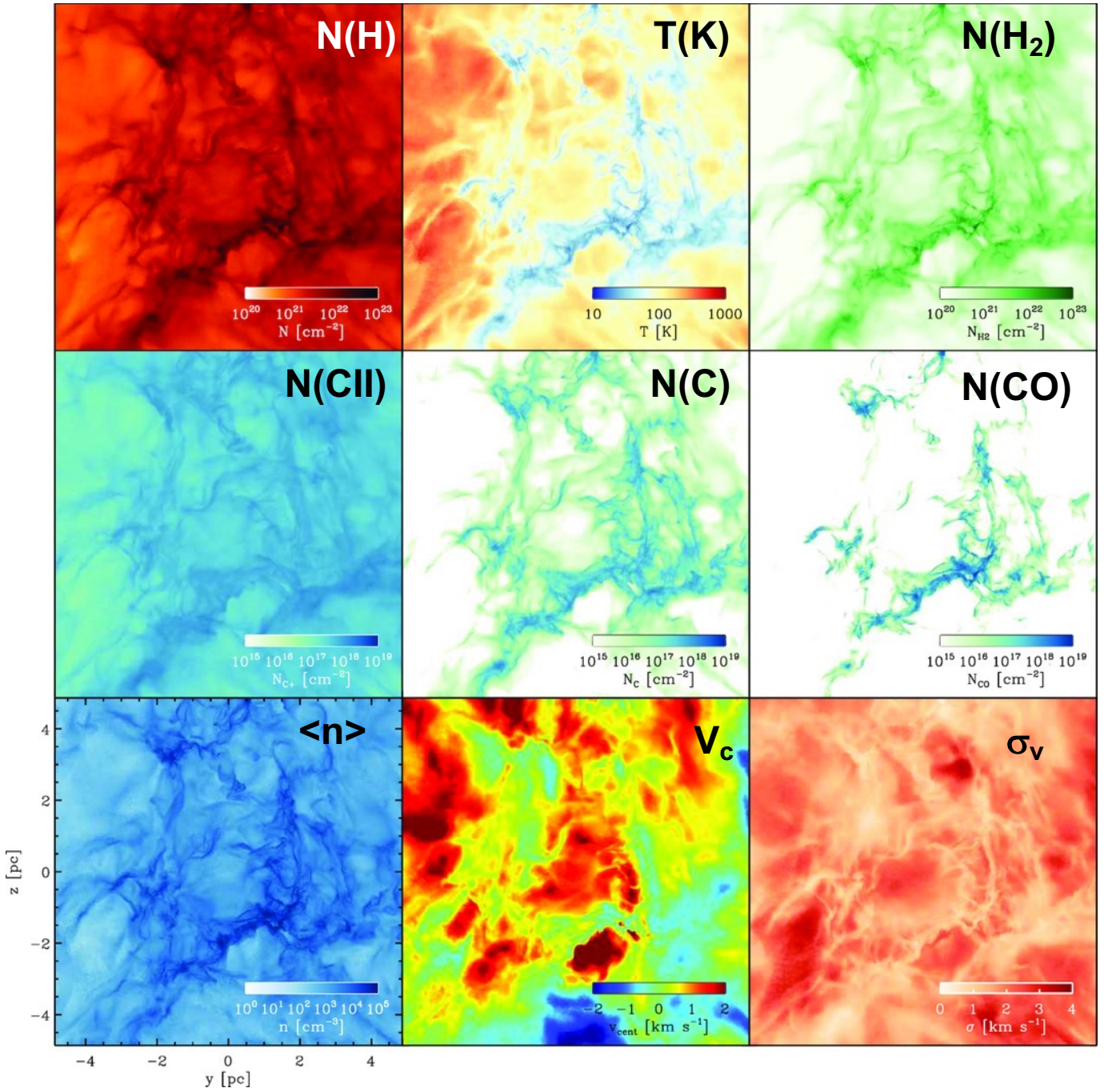


Clark+ 2012

vflow=+/-6.8 km/s

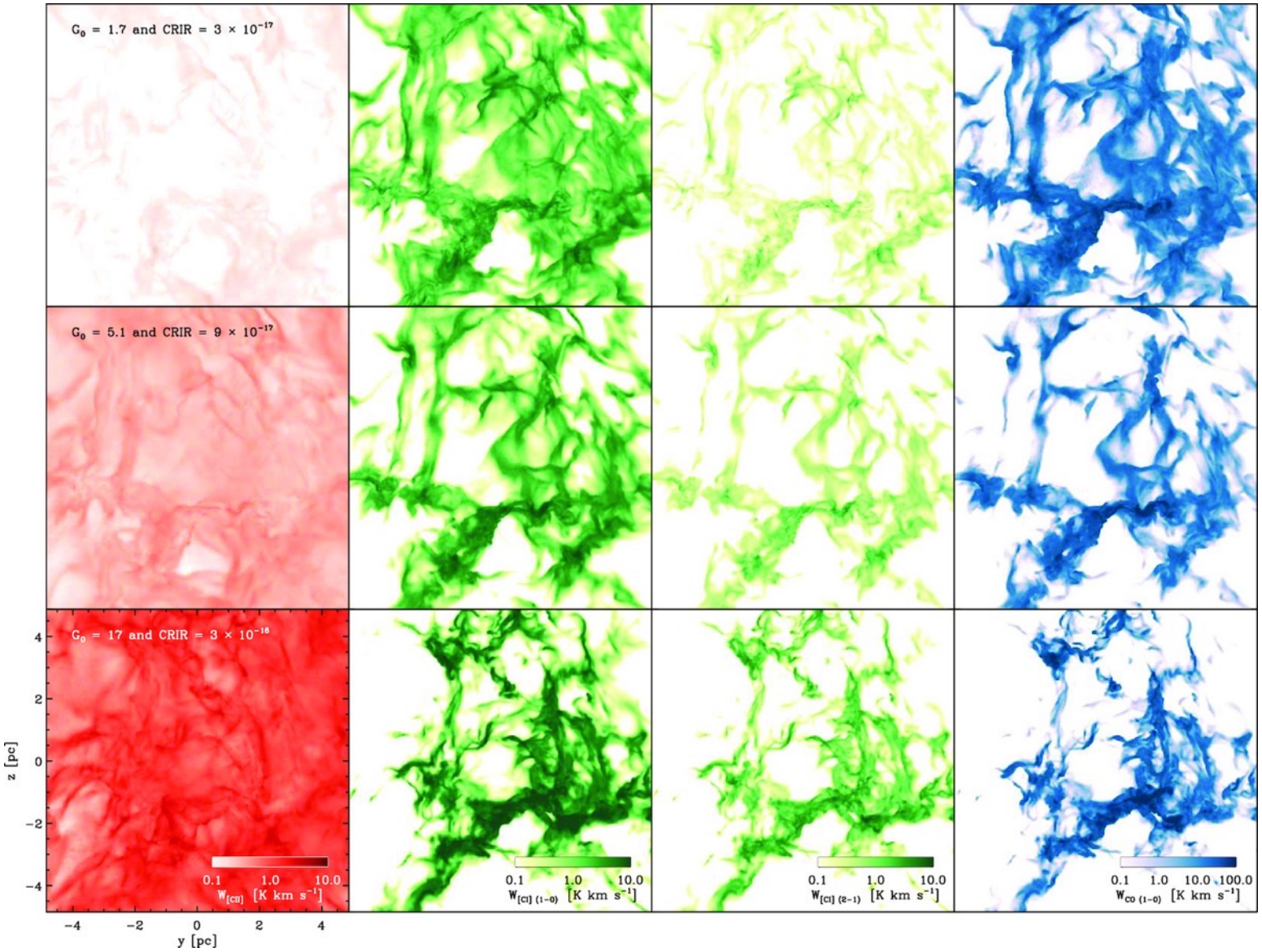


G_O=17
CRIR=3x10^{-16}



W([CII]) W([CI])$_{1-0}$ W([CI]) $_{2-1}$ W(CO) $_{1-0}$

G_O=1.7 CRIR=3x10^{-17}

G_O=5.1 CRIR=9x10^{-17}

G_O=17 CRIR=3x10^{-16}