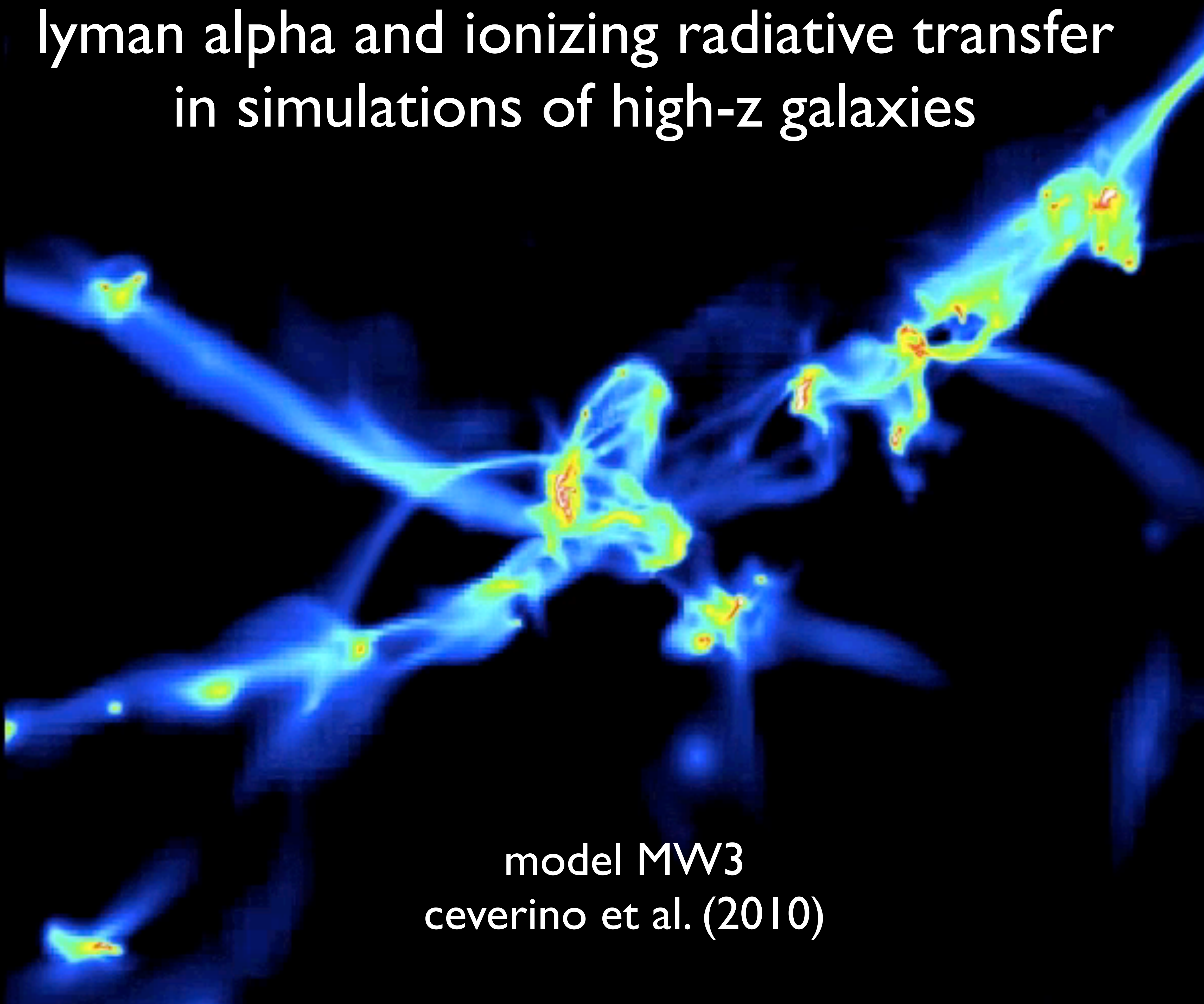
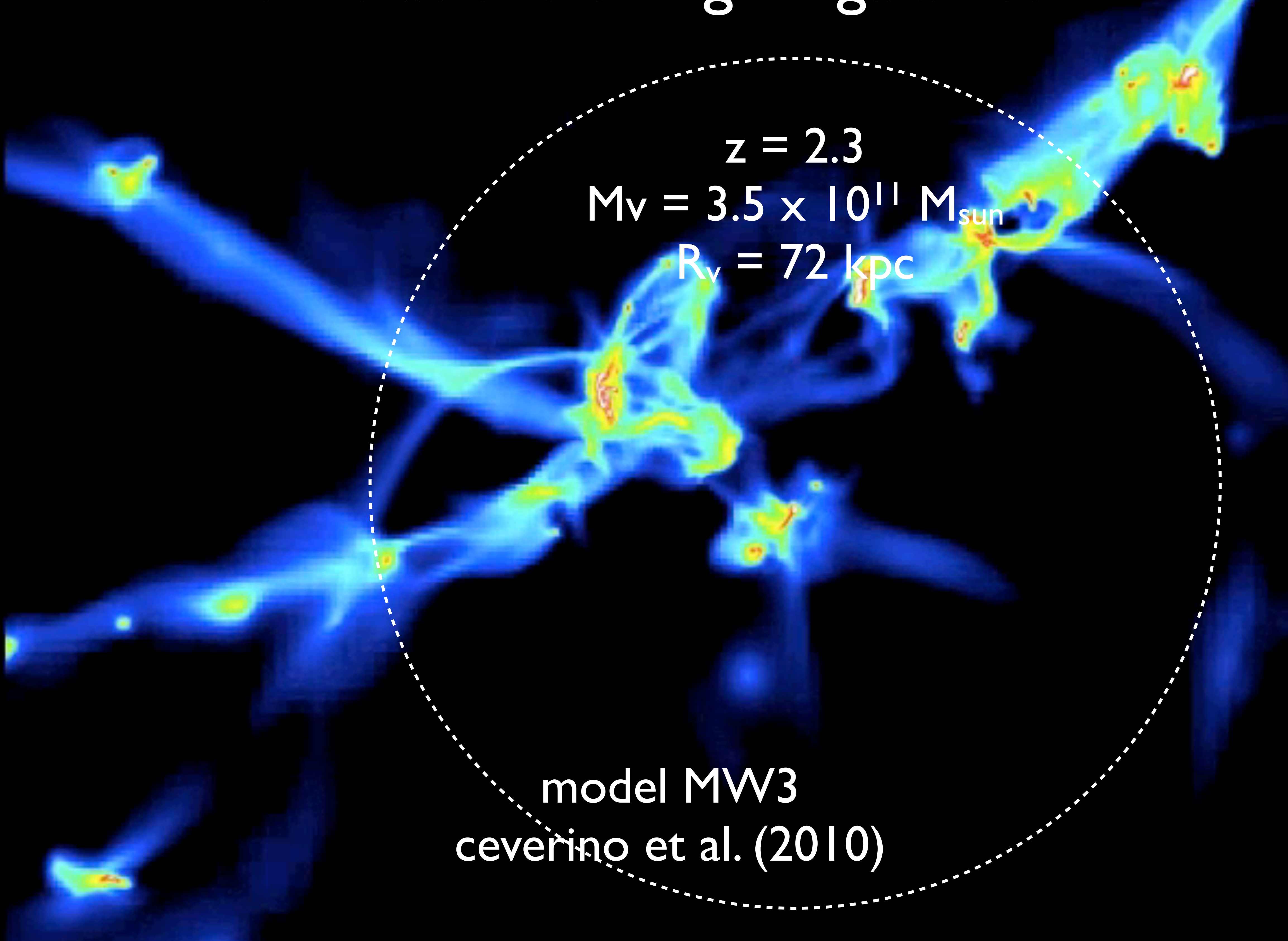
daniel ceverino, avishai dekel, michele fumagalli,
joel primack, x prochaska

lyman alpha and ionizing radiative transfer in simulations of high-z galaxies



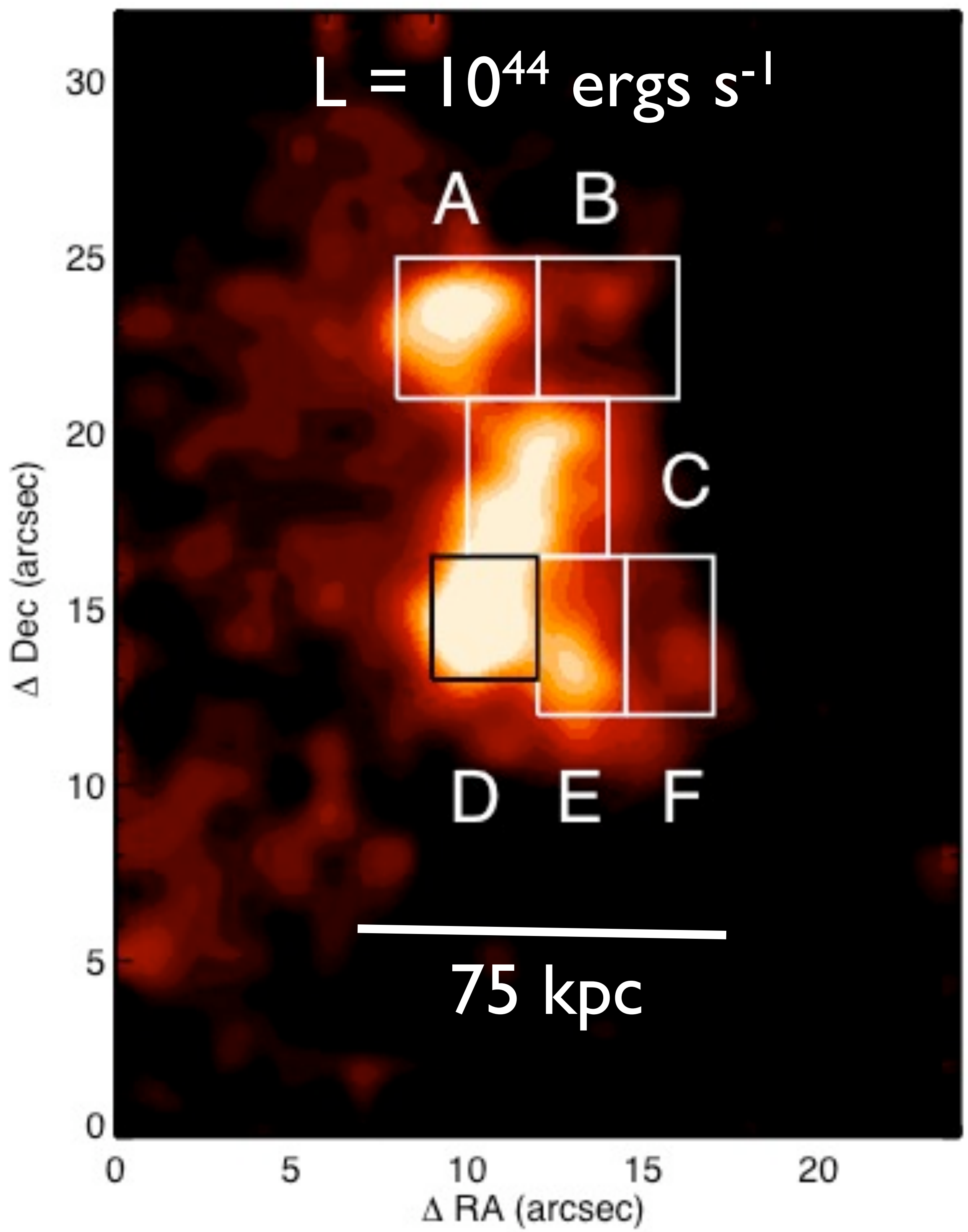
model MW3
ceverino et al. (2010)

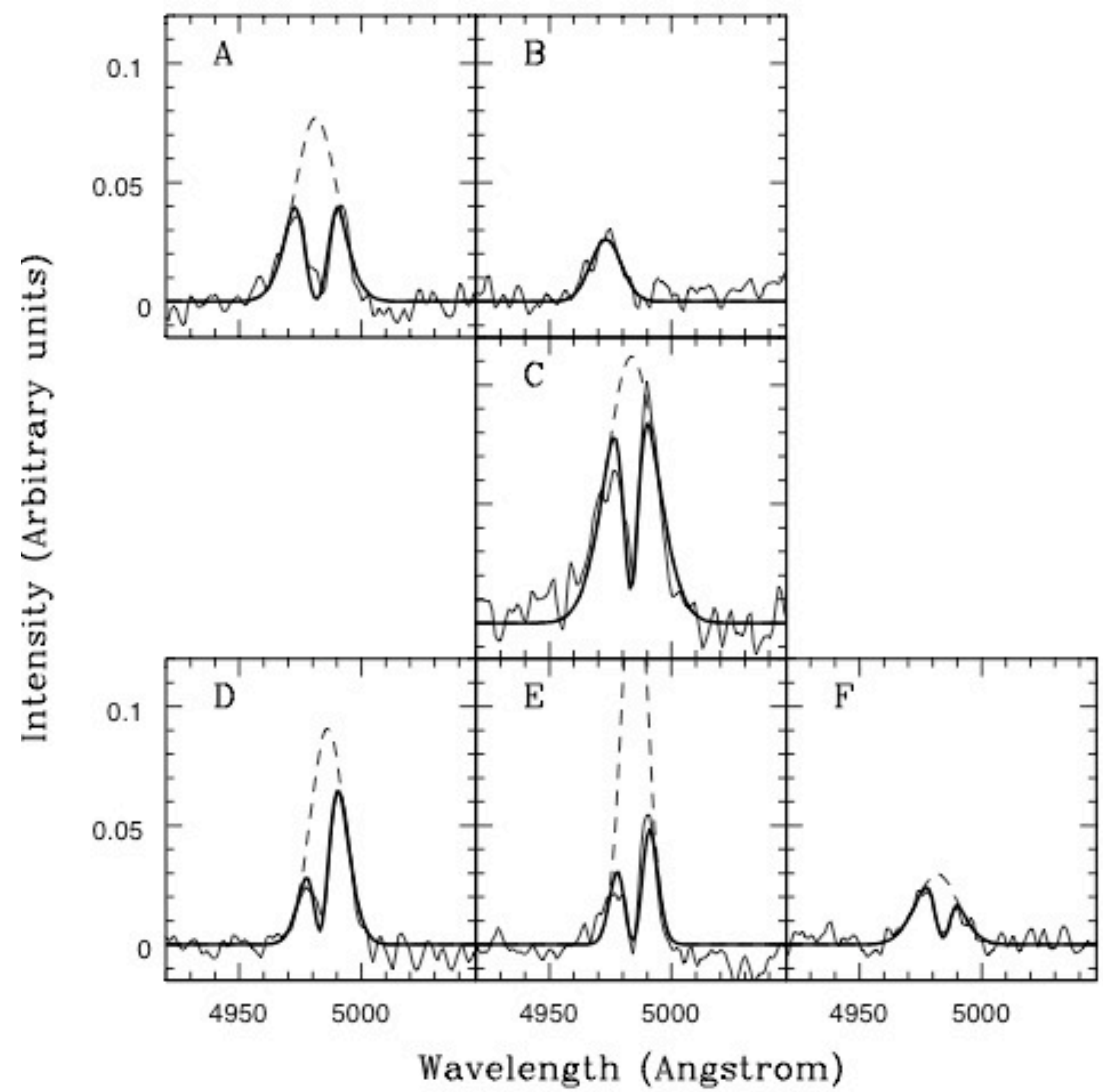
lyman alpha and ionizing radiative transfer in simulations of high-z galaxies

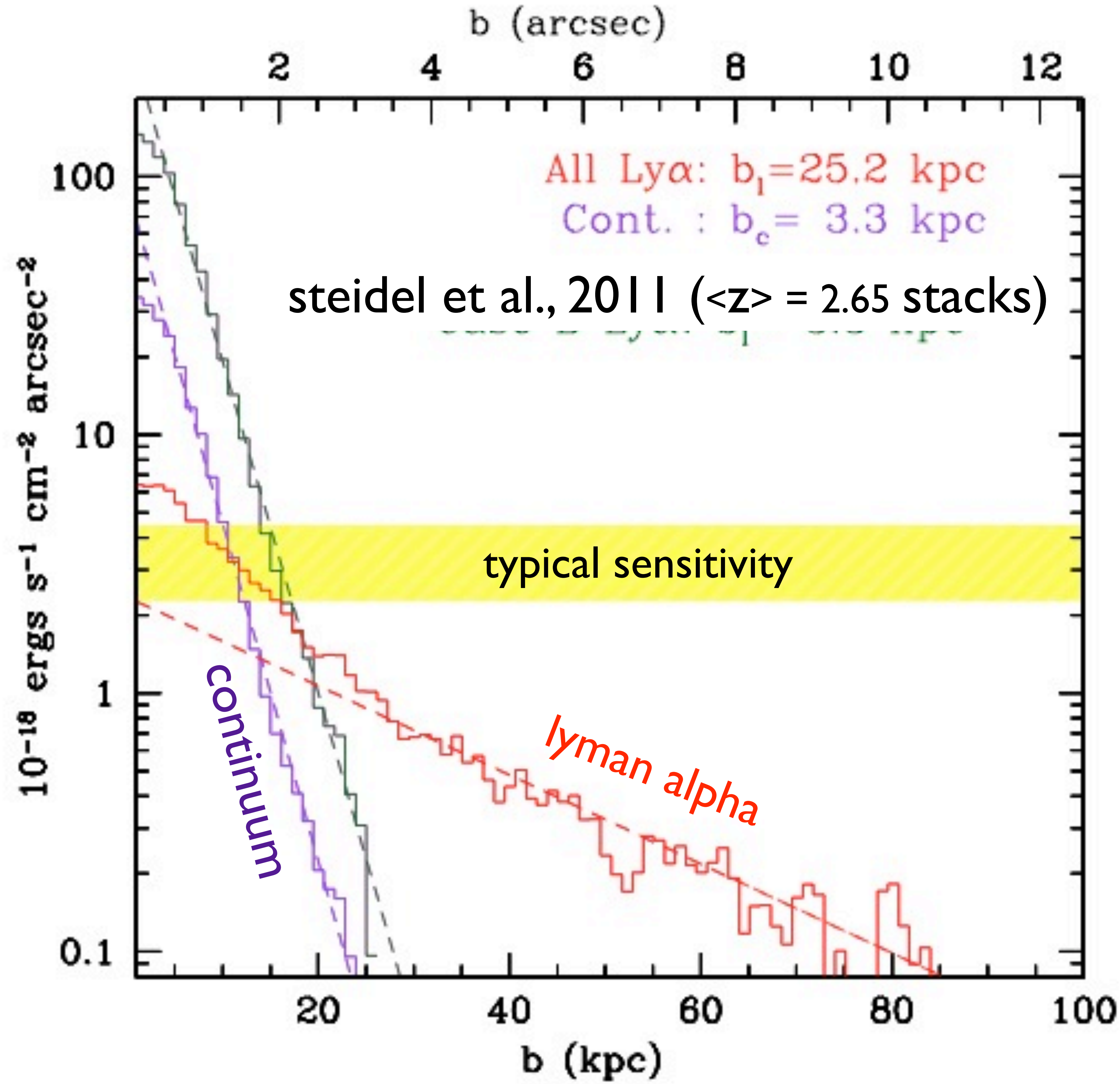


Lyman alpha blobs

LAB 2 (z = 3.09) wilman et al., 2005





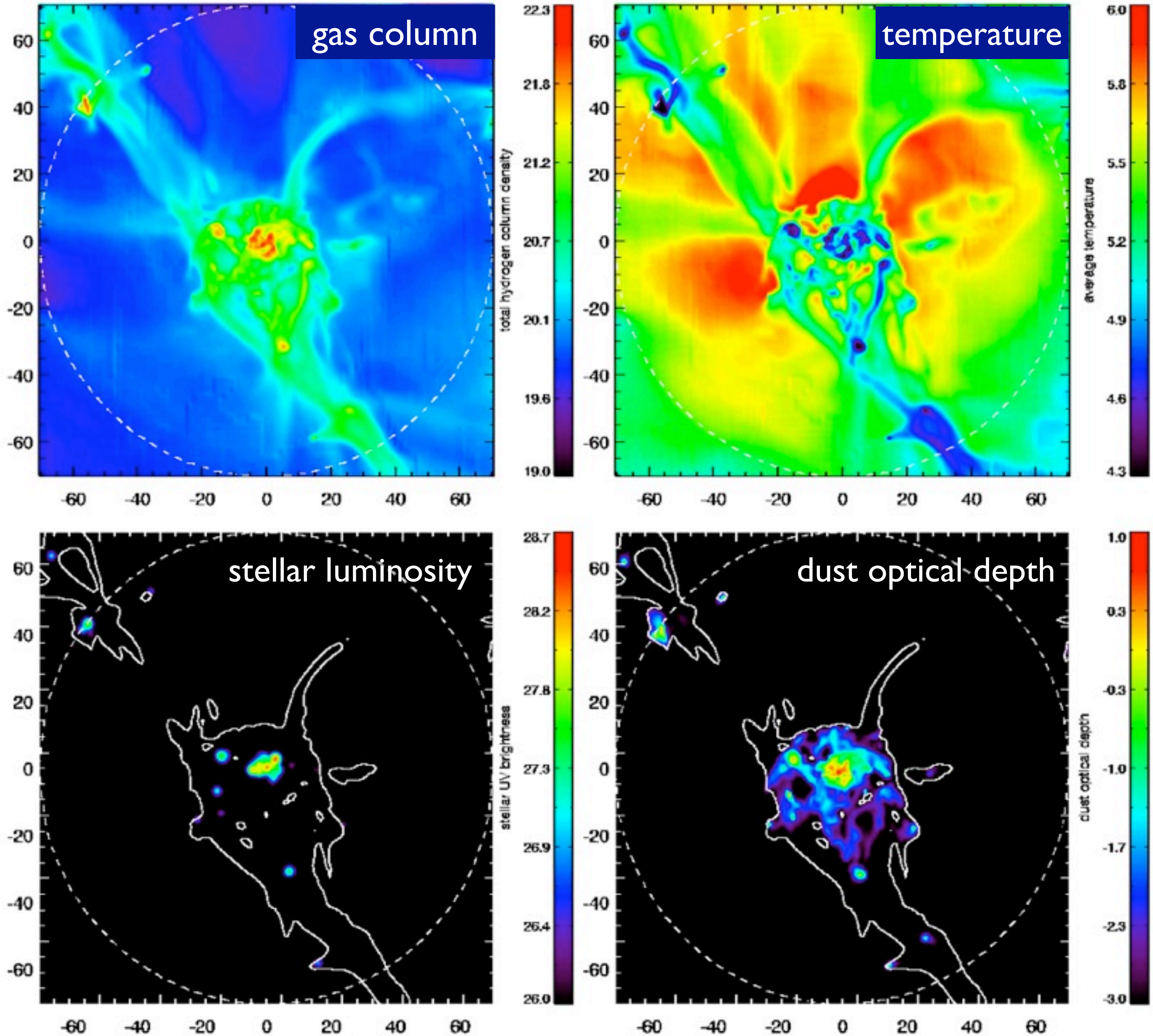


b (arcsec)
2
4
6
8
10
12
All Lyα: b_l=25.2 kpc
Cont. : b_c= 3.3 kpc
steidel et al., 2011 (<z> = 2.65 stacks)
typical sensitivity
continuum
lyman alpha
100
10
1
0.1
10^-18 ergs s^-1 cm^-2 arcsec^-2
20
40
60
80
100
b (kpc)

origin of the lyman alpha blobs

- cooling emission from infall
  e.g., haiman+ 2000, fadal+ 2001, dijkstra&loeb 2009, goerdt+ 2010, faucher-giguere+ 2010
- photoionization by stars
  but c.f. matsuda+ 2004, nilsson+ 2006
- photoionization by AGN
  e.g., geach+ 2009
- scattering in circumgalactic gas/outflows
  e,g., zheng+ 2010, steidel+ 2011

what does theory predict when line scattering, photoionization and dust are taken into account?


gas column
total hydrogen column density
temperature
average temperature
stellar luminosity
stellar UV brightness
dust optical depth
dust optical depth

transport of ionizing and Lα radiation

multi-wavelength monte carlo transport

no on the spot approximation

arbitrary distribution of ionizing sources

isotropic UVB plus ~5000 star particles

using an AMR grid

10 levels of refinement, $\Delta x \sim 60$ pc for 280 kpc box

dust absorption + scattering included

dust opacity constructed from metal distribution

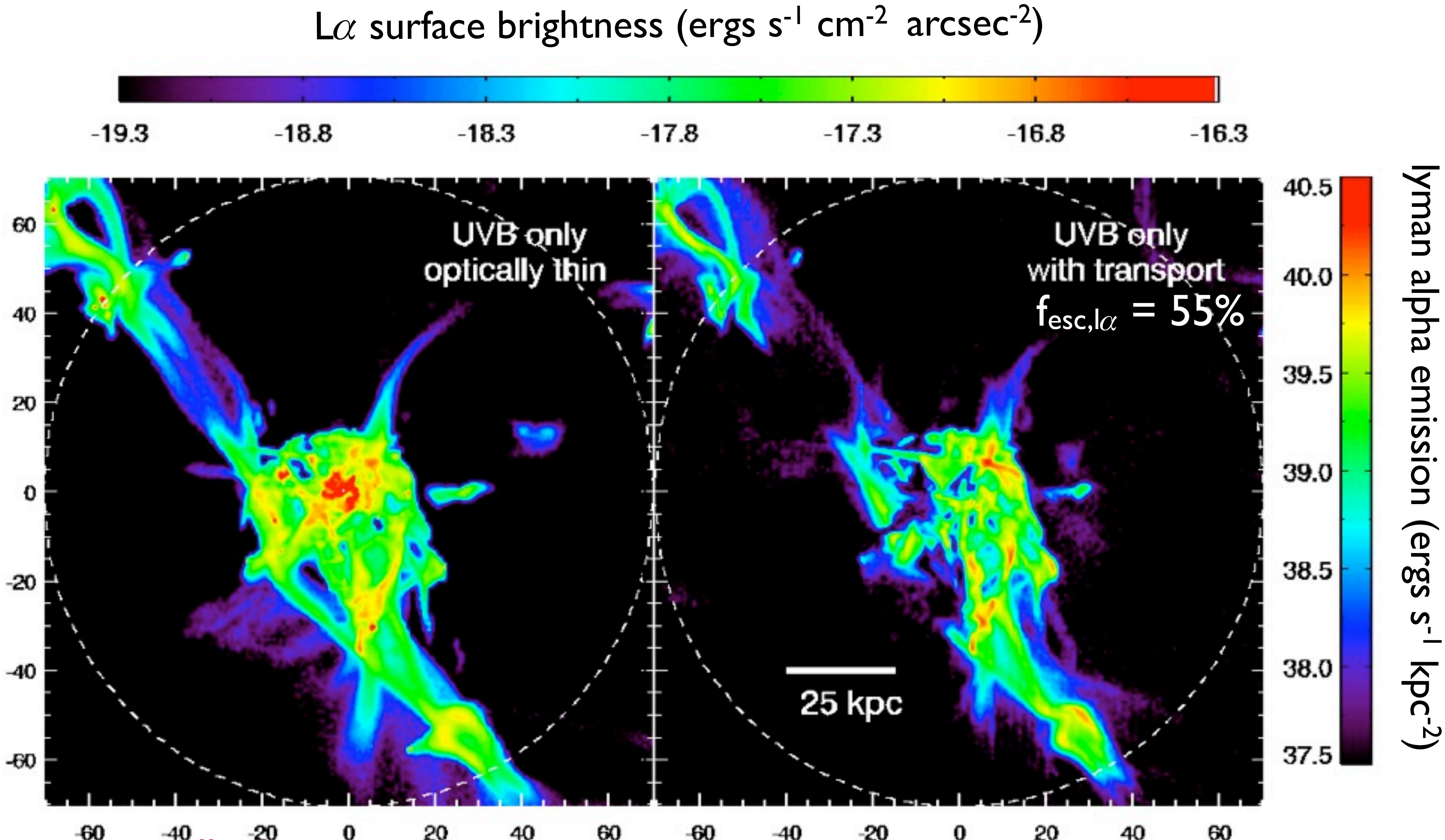
transport done in post-processing

assumes ionization equilibrium, approximate heating

scattering/absorption on unresolved scales?

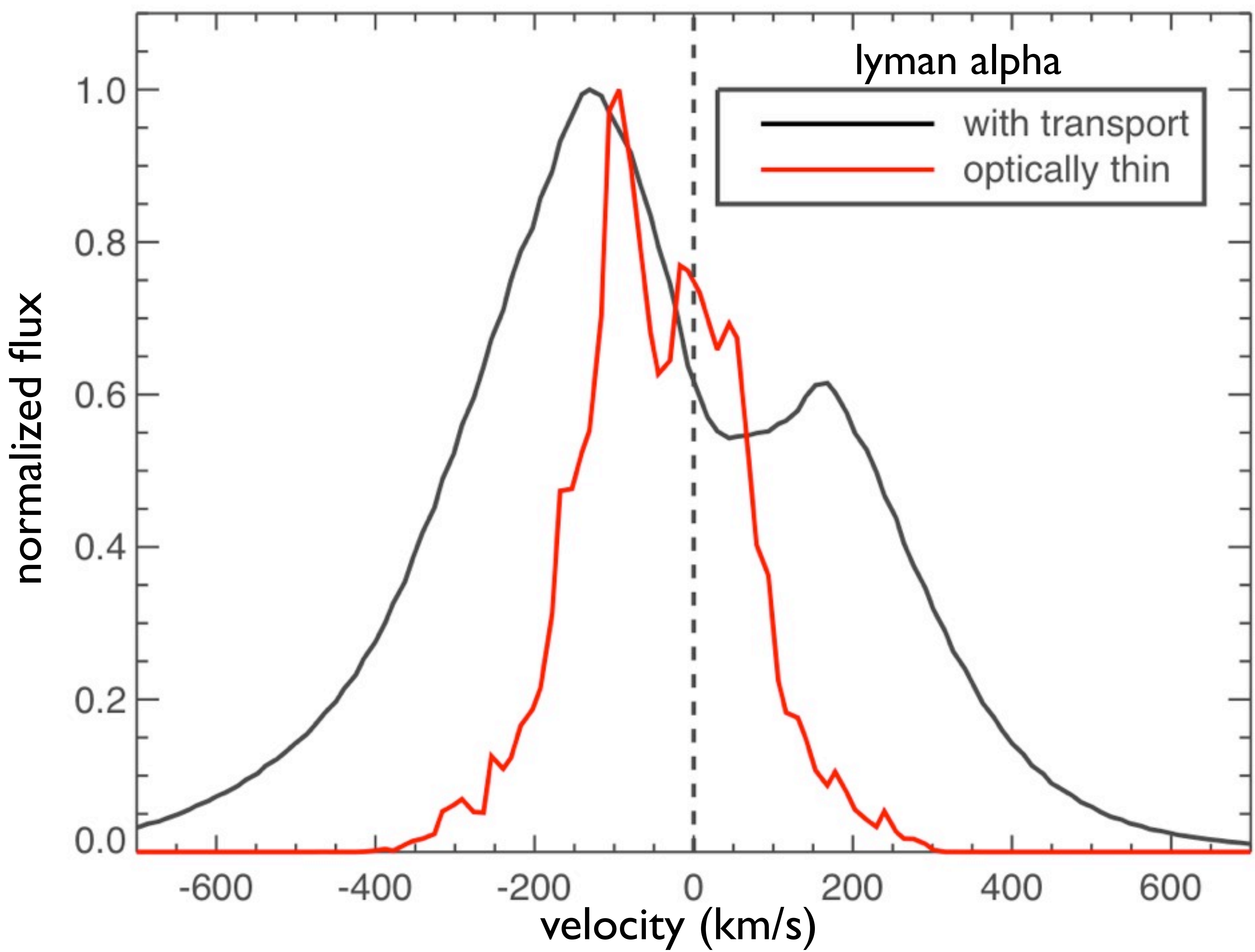
lyman alpha cooling emission

no stellar or AGN photoionization; $L = 7 \times 10^{42}$ ergs/s



optically thin approximation
e.g., goerdt et al. (2010)

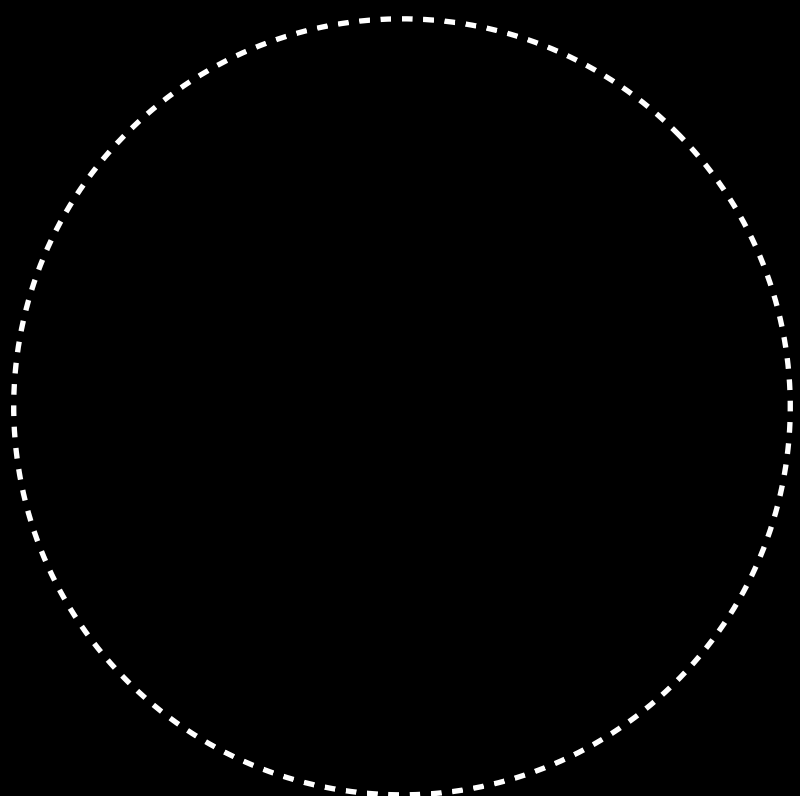
with line scattering and dust



lyman alpha
with transport
optically thin
normalized flux
velocity (km/s)
1.0
0.8
0.6
0.4
0.2
0.0
-600
-400
-200
0
200
400
600

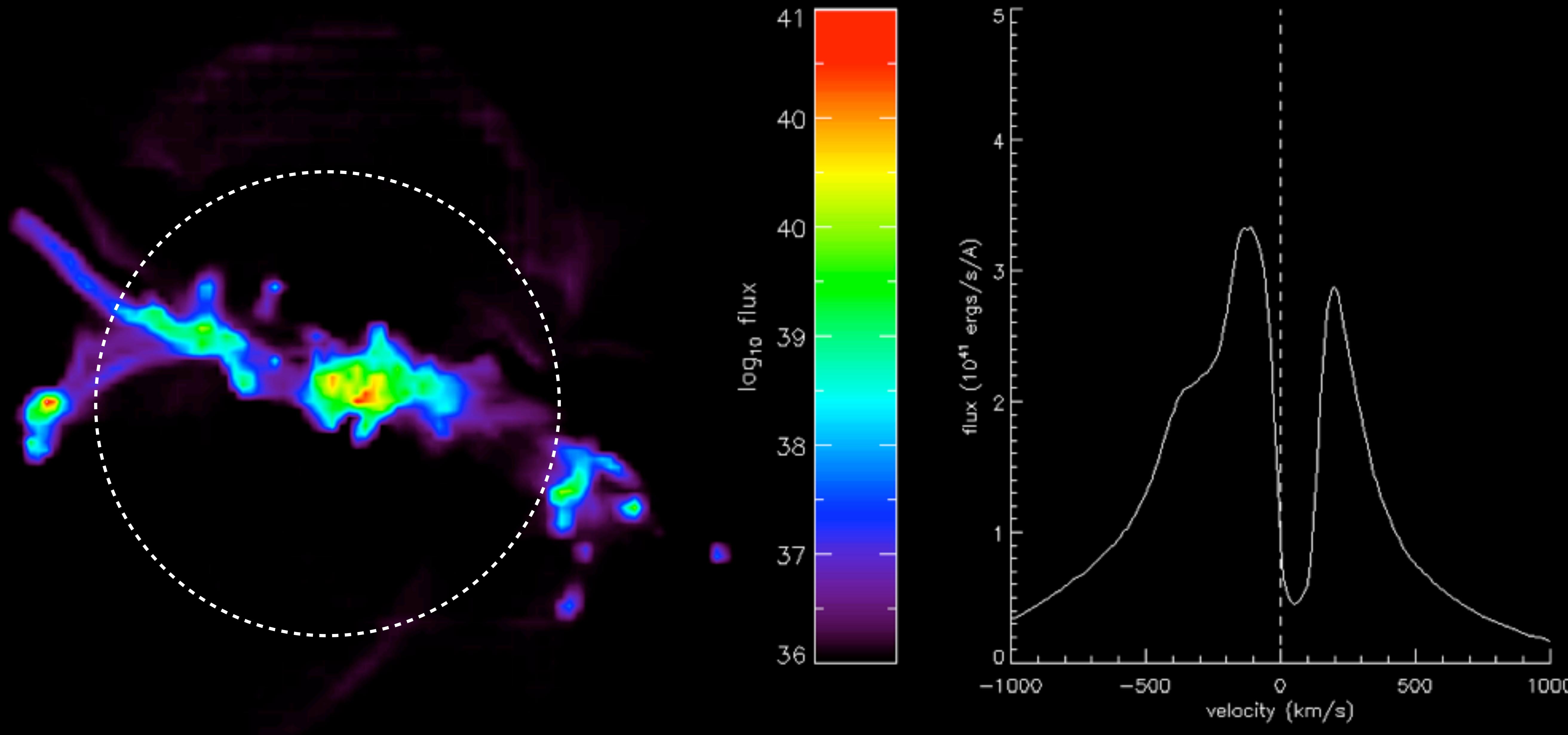
orientation dependence of Lα emission

MW3 z = 2.33 (cooling emission, no photoionization)



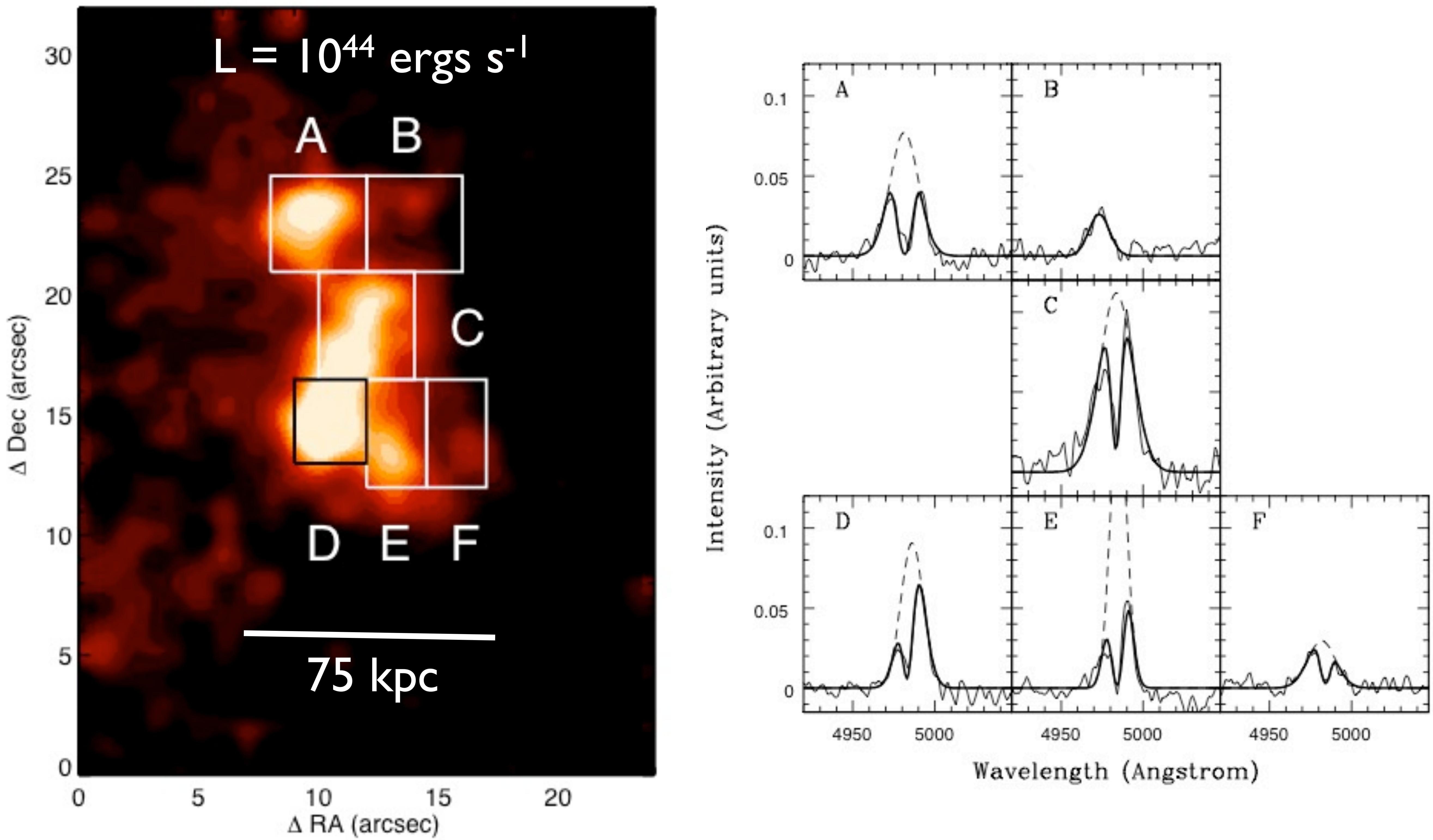
orientation dependence of Lα emission

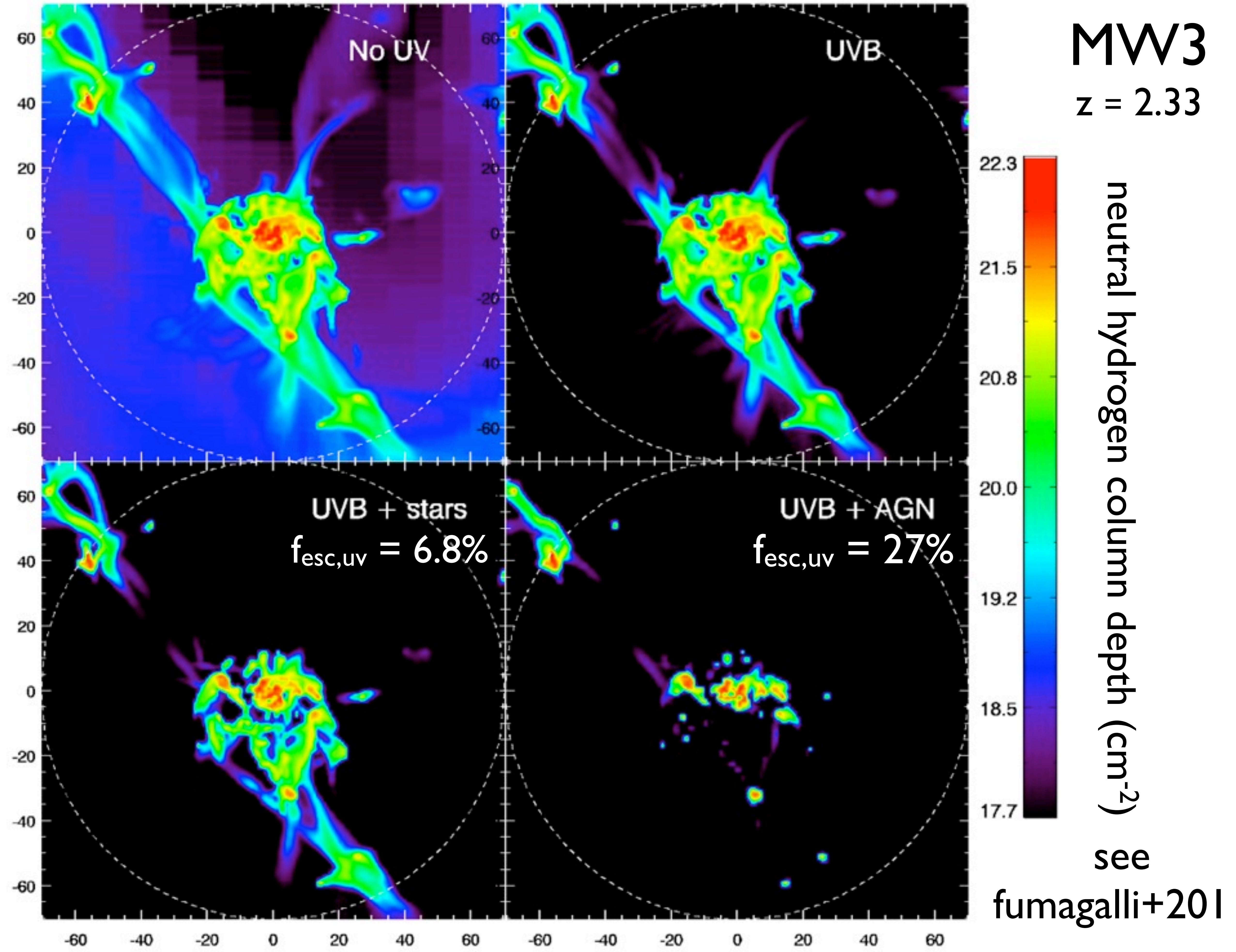
MW3 z = 2.33 (cooling emission, no photoionization)



Lyman alpha blobs

LAB 2 (z = 3.09) wilman et al., 2005





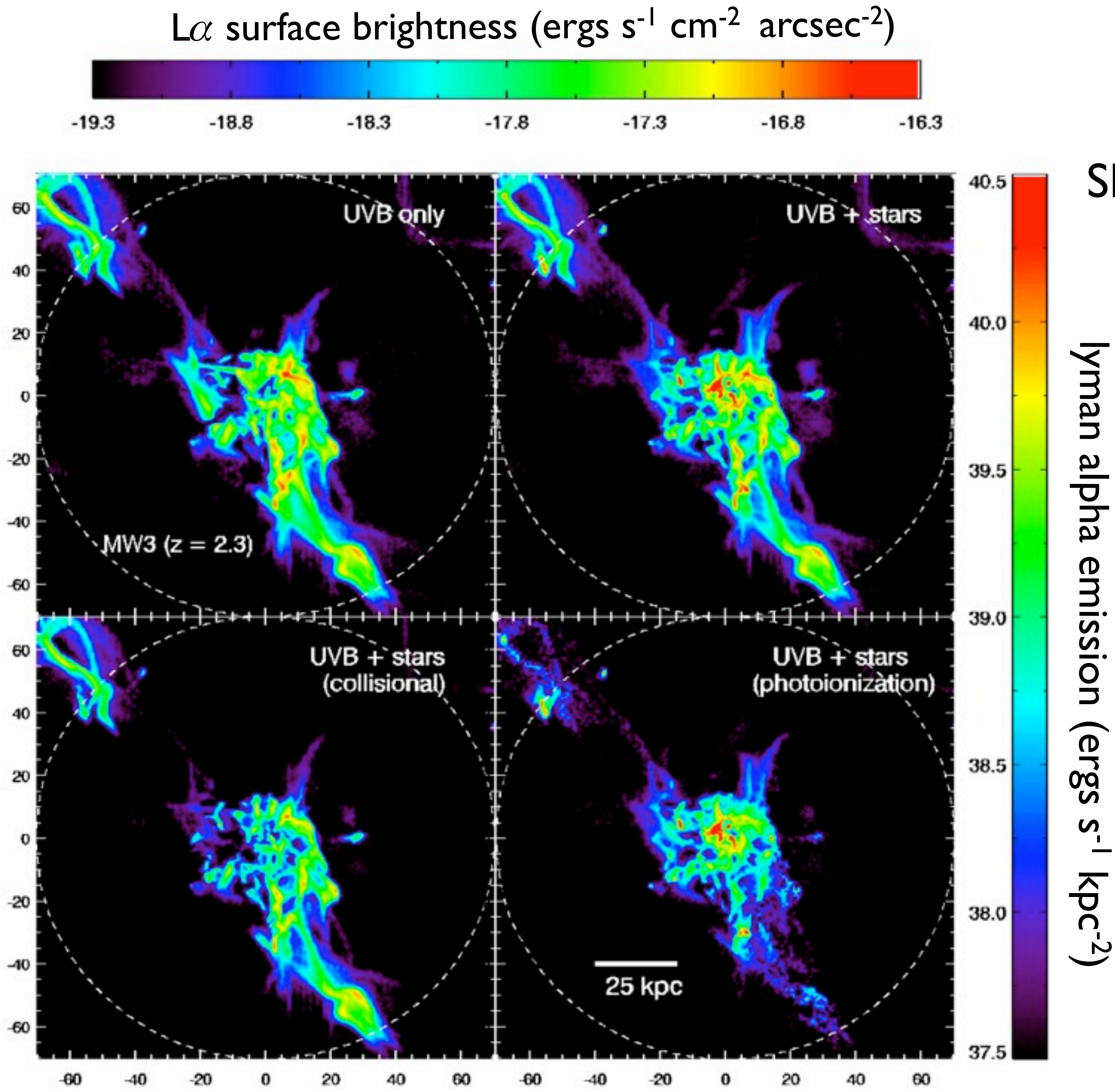
MW3
z = 2.33
No UV
UVB
UVB + stars
f_esc,uv = 6.8%
UVB + AGN
f_esc,uv = 27%
22.3
21.5
20.8
20.0
19.2
18.5
17.7
neutral hydrogen column depth (cm-2)
60
40
20
0
-20
-40
-60
see
fumagalli+2011

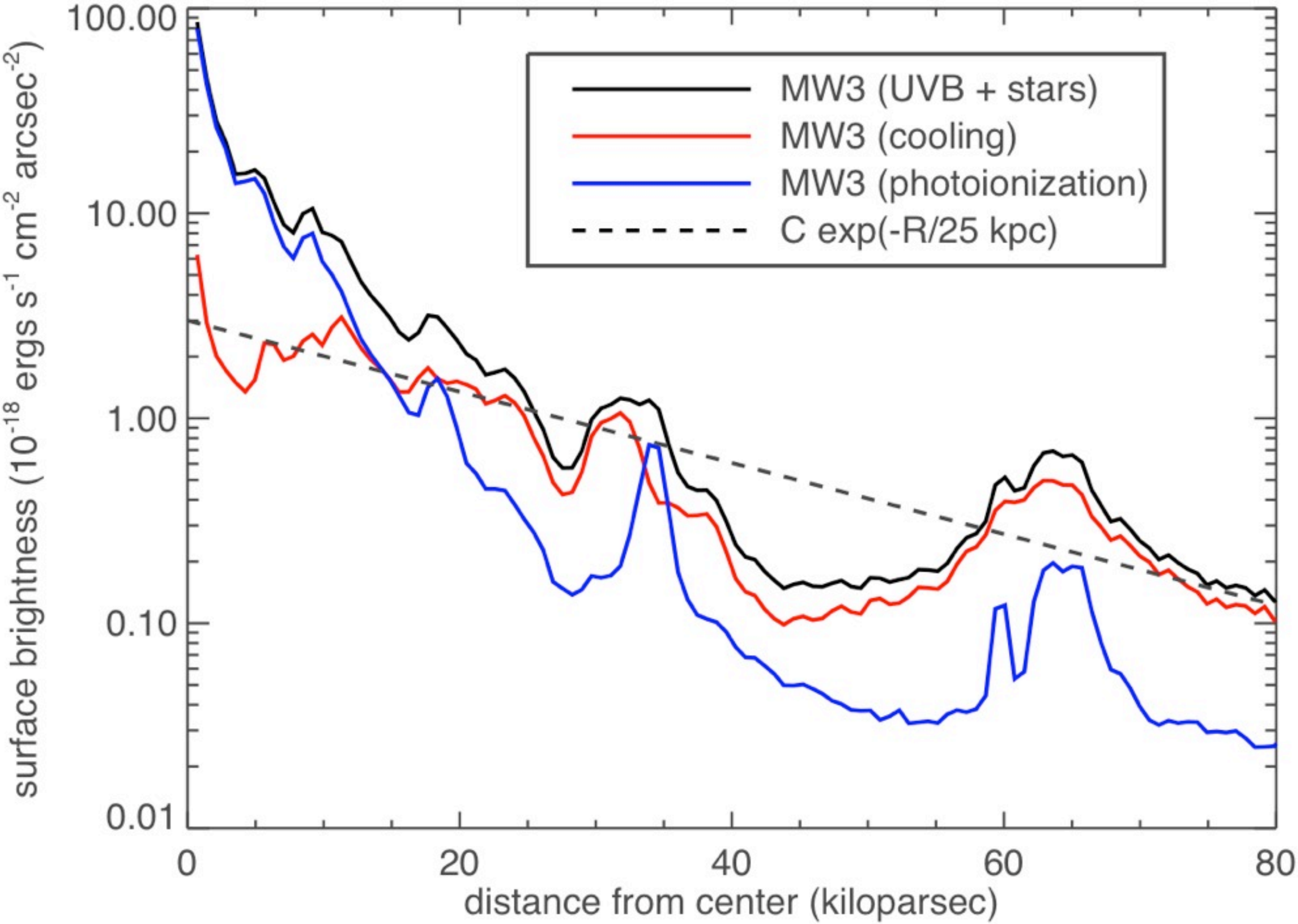
MW3

z = 2.33

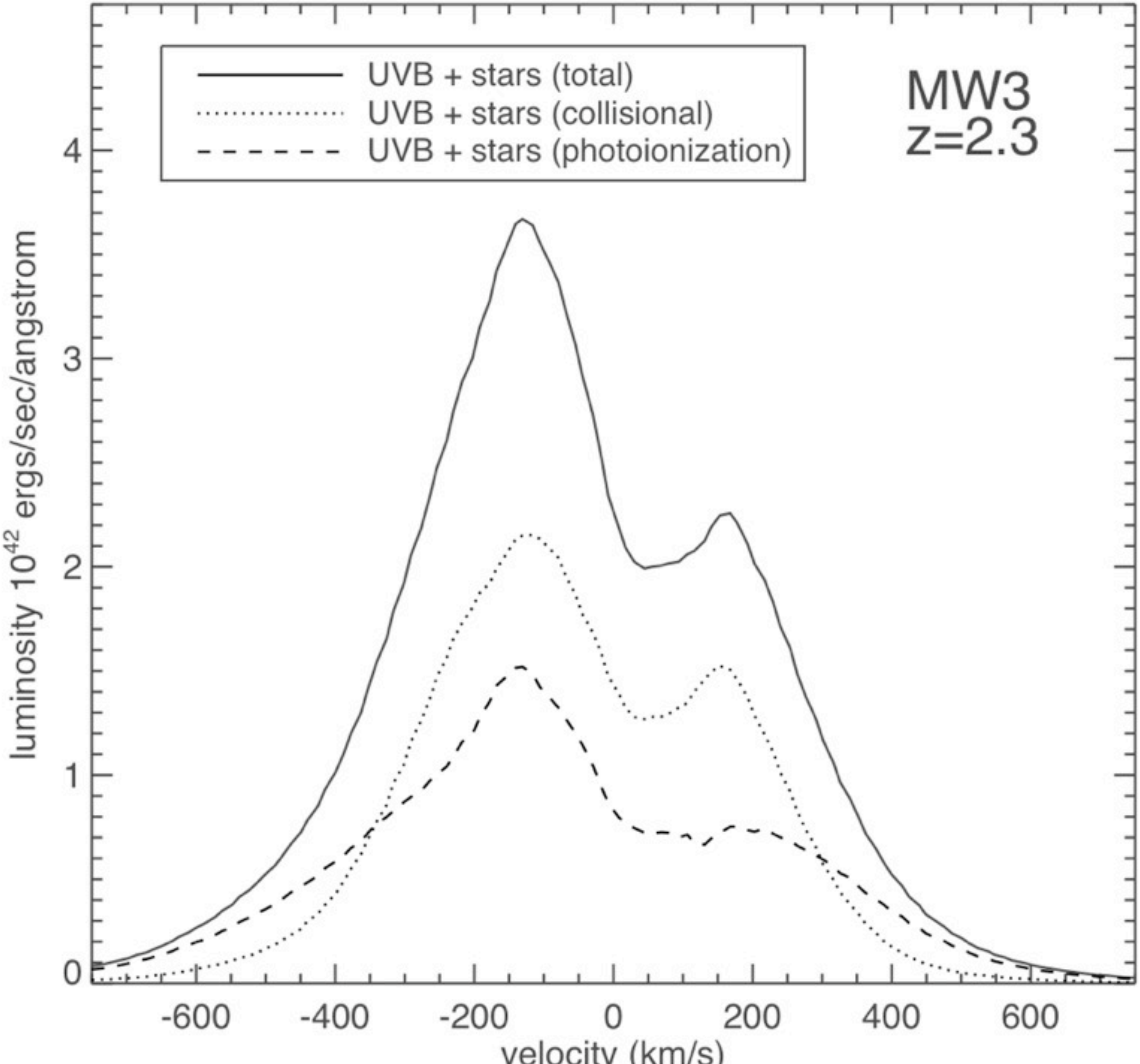
SFR = 30 M_{sun}/yr

$f_{esc,L\alpha}$ = 5%





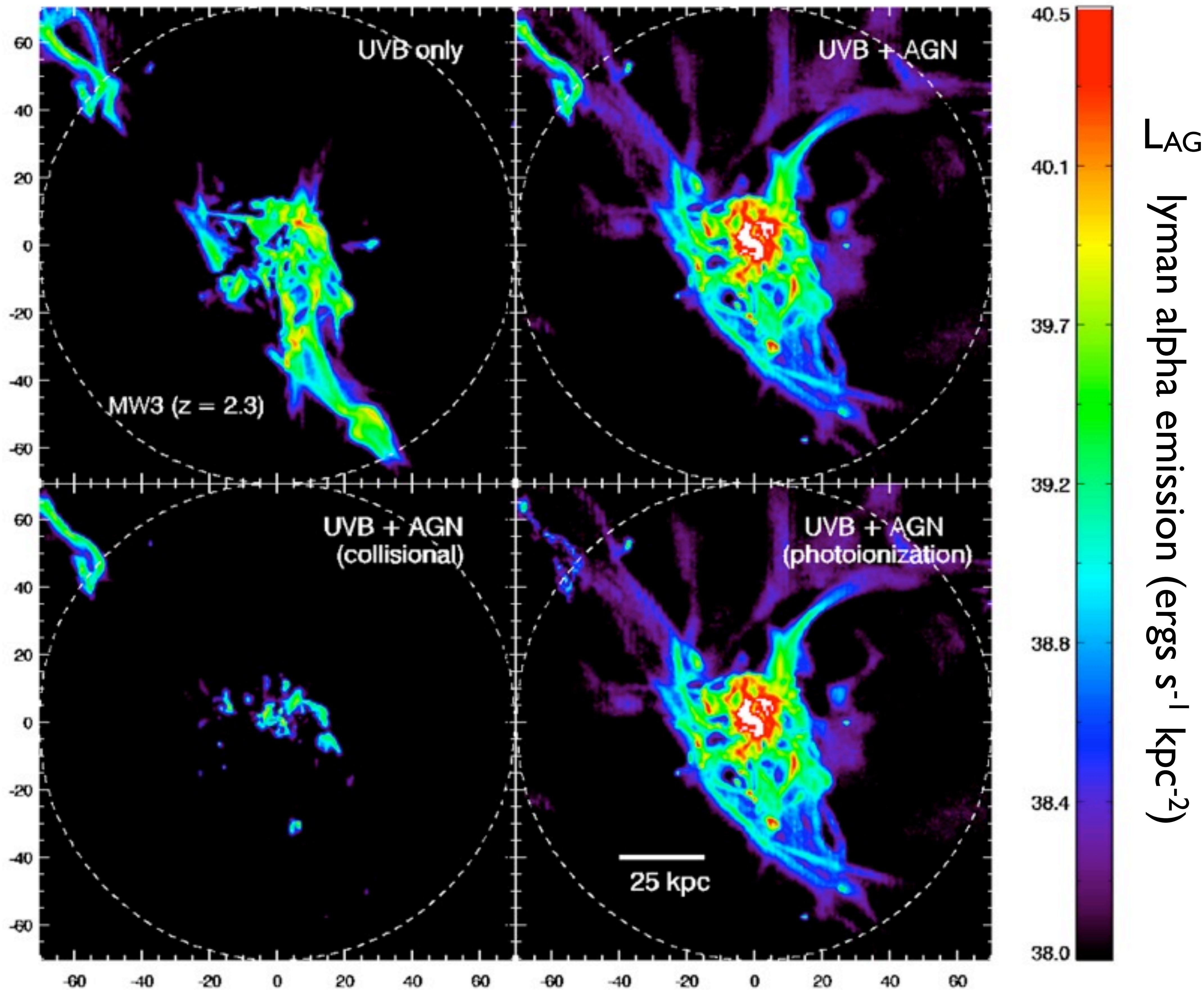
MW3 (UVB + stars)
MW3 (cooling)
MW3 (photoionization)
C exp(-R/25 kpc)
surface brightness (10^{-18} ergs s^{-1} cm^{-2} $arcsec^{-2}$)
100.00
10.00
1.00
0.10
0.01
0
20
40
60
80
distance from center (kiloparsec)

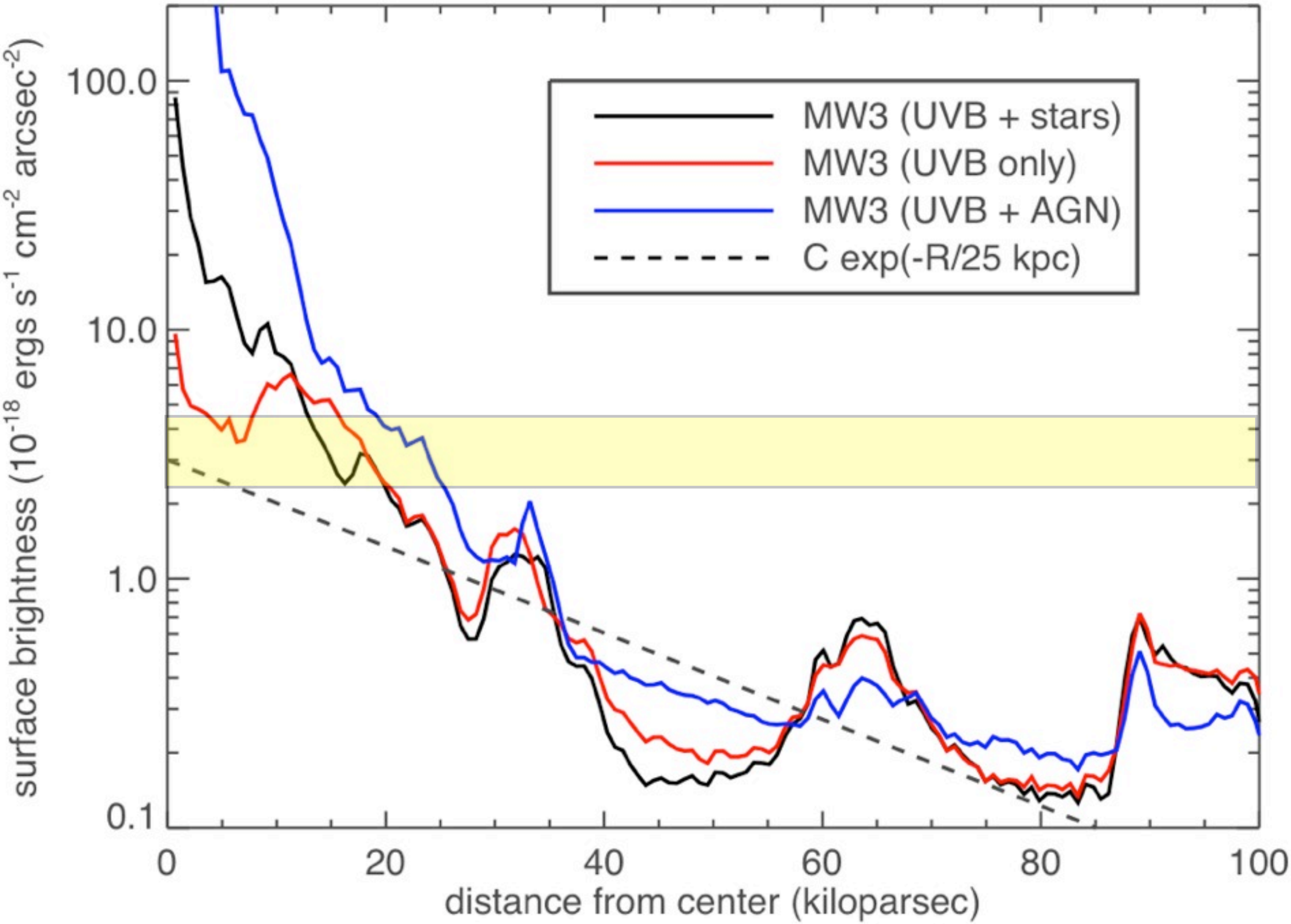

UVB + stars (total)
UVB + stars (collisional)
UVB + stars (photoionization)
MW3
z=2.3
luminosity 10^{42} ergs/sec/angstrom
0
1
2
3
4
-600
-400
-200
0
200
400
600
velocity (km/s)

MW3

z = 2.33

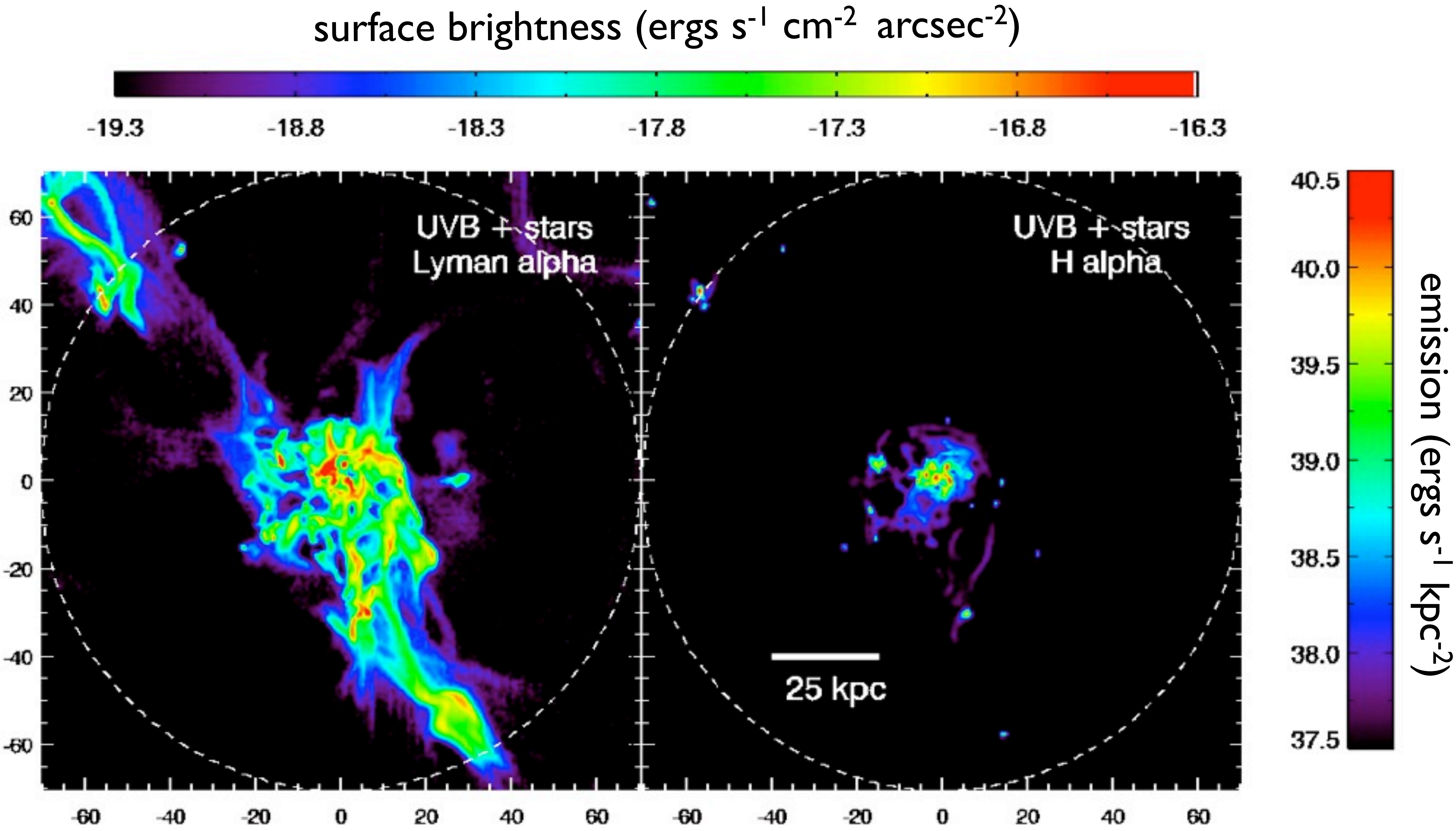
$L_{AGN} = 10^{45}$ ergs/s

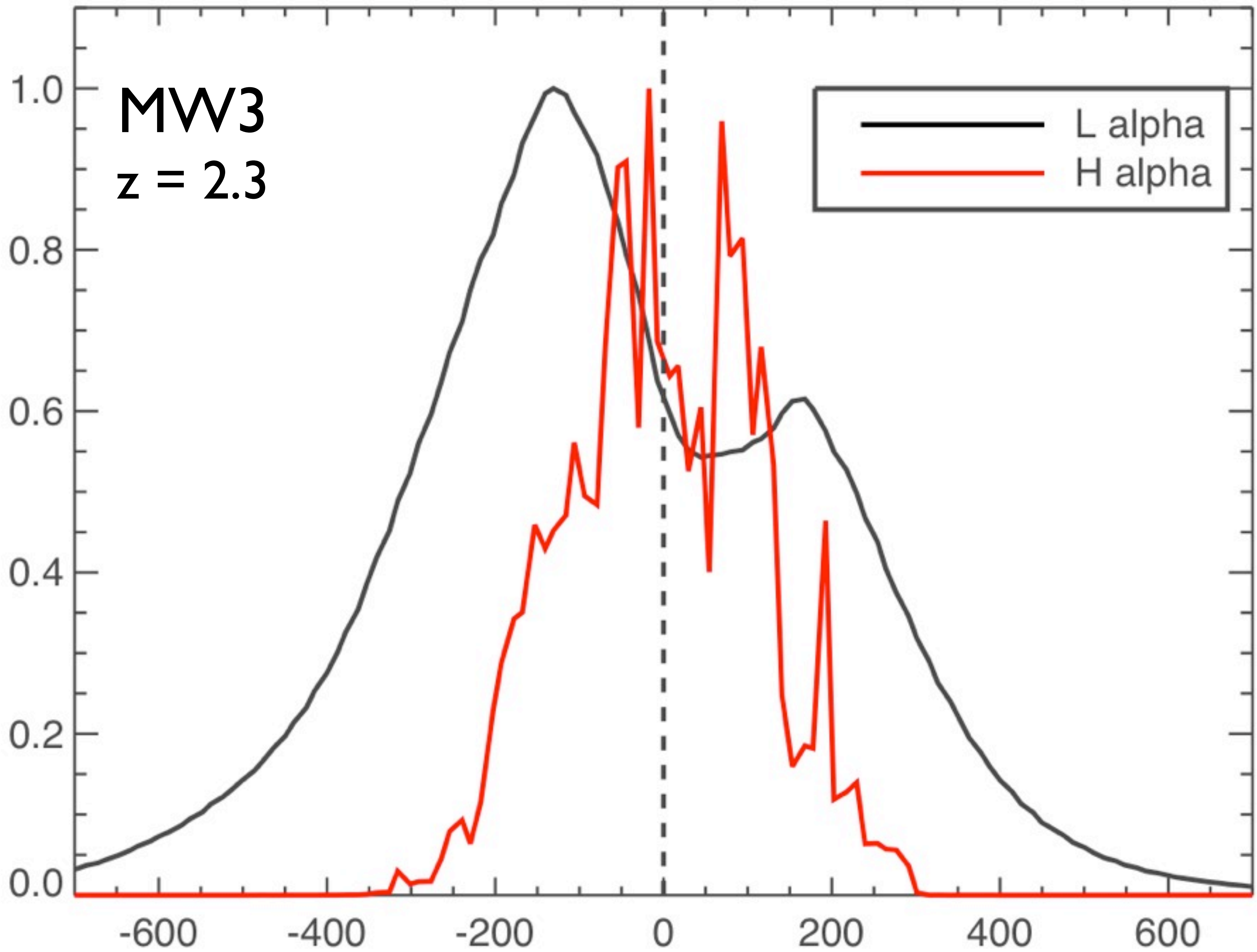




surface brightness (10^-18 ergs s^-1 cm^-2 arcsec^-2)
100.0
10.0
1.0
0.1
MW3 (UVB + stars)
MW3 (UVB only)
MW3 (UVB + AGN)
C exp(-R/25 kpc)
0
20
40
60
80
100
distance from center (kiloparsec)

H alpha from photoionization

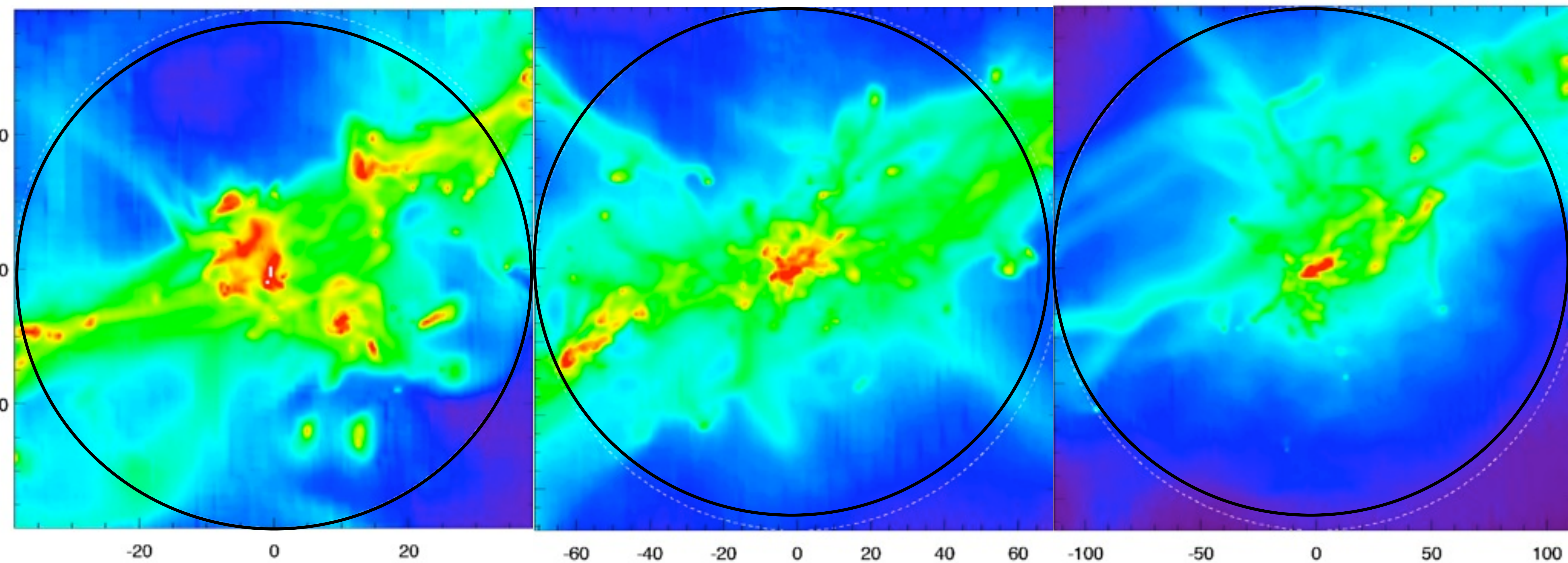



MW3
z = 2.3
L alpha
H alpha
1.0
0.8
0.6
0.4
0.2
0.0
-600
-400
-200
0
200
400
600

dependence on mass/redshift

model SFG1

gas column density



z = 4.5
R_v = 39 kpc

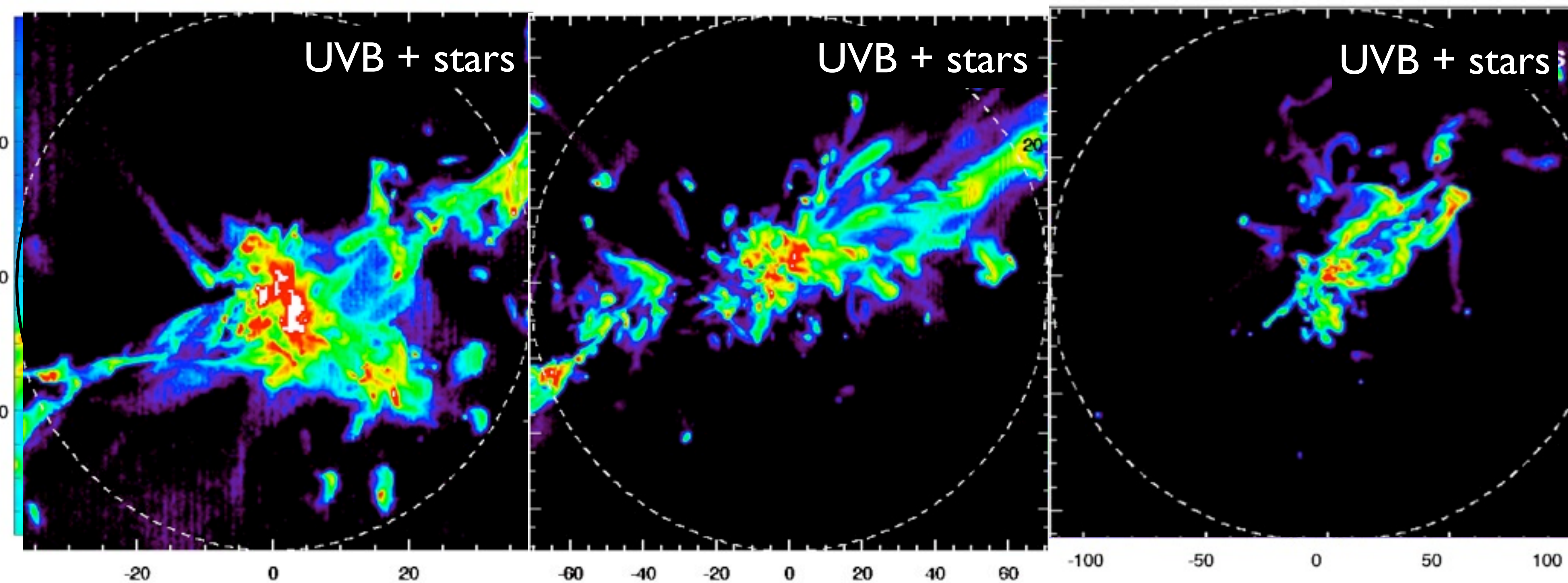
z = 3.5
R_v = 71 kpc

z = 2.3
R_v = 114 kpc

dependence on mass/redshift

model SFG1

lyman alpha emission



z = 4.5
R_v = 39 kpc

z = 3.5
R_v = 71 kpc

z = 2.3
R_v = 114 kpc

summary

Extended lyman alpha emission (blobs) a multi-faceted phenomenon

Cooling emission with transport produces general features of some LABs
(but line profiles, temperature uncertainty?)

Photoionization by stars/AGN produces extended emission tracing out circumgalactic gas

No scattering in outflows here, but we should consider a multi-phase medium