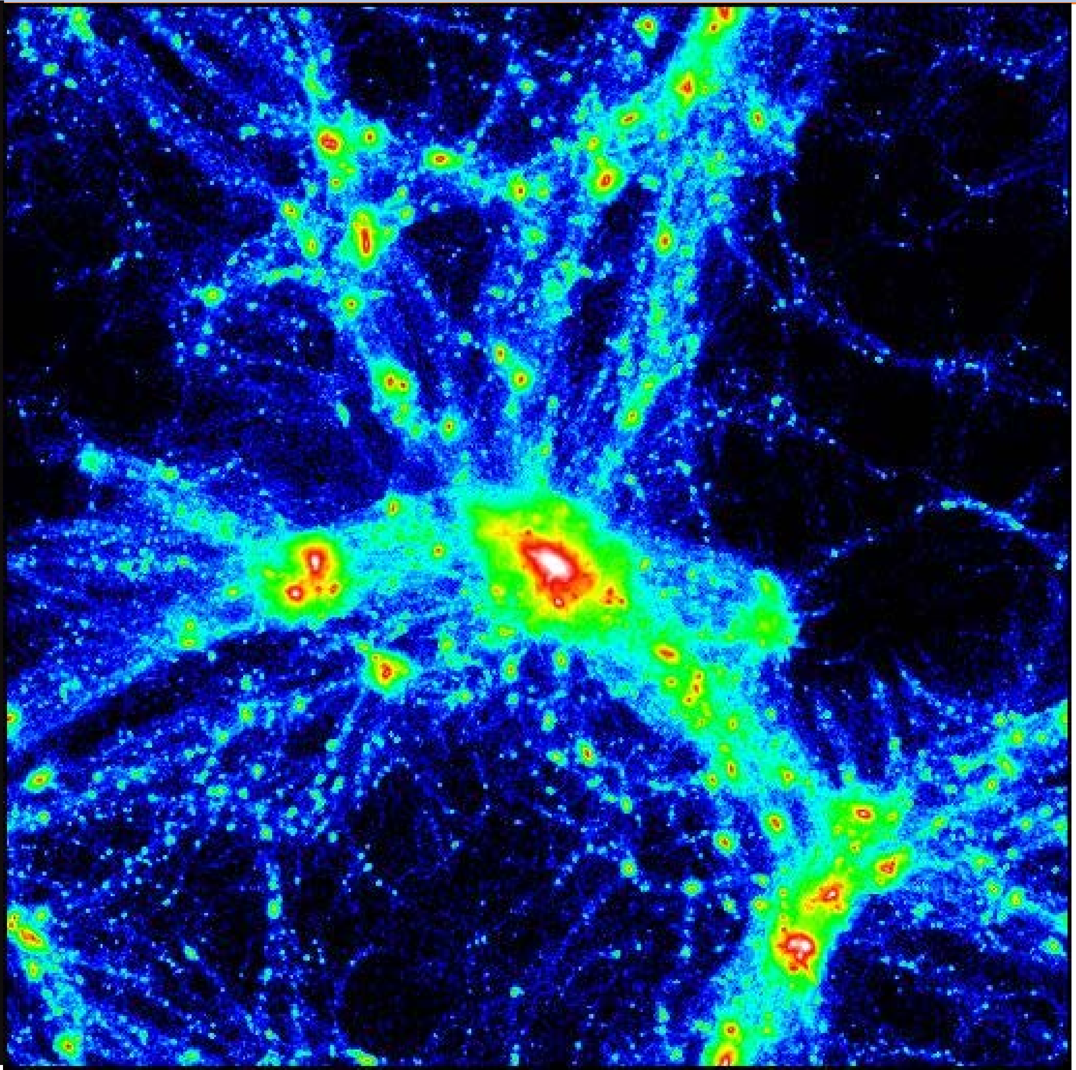
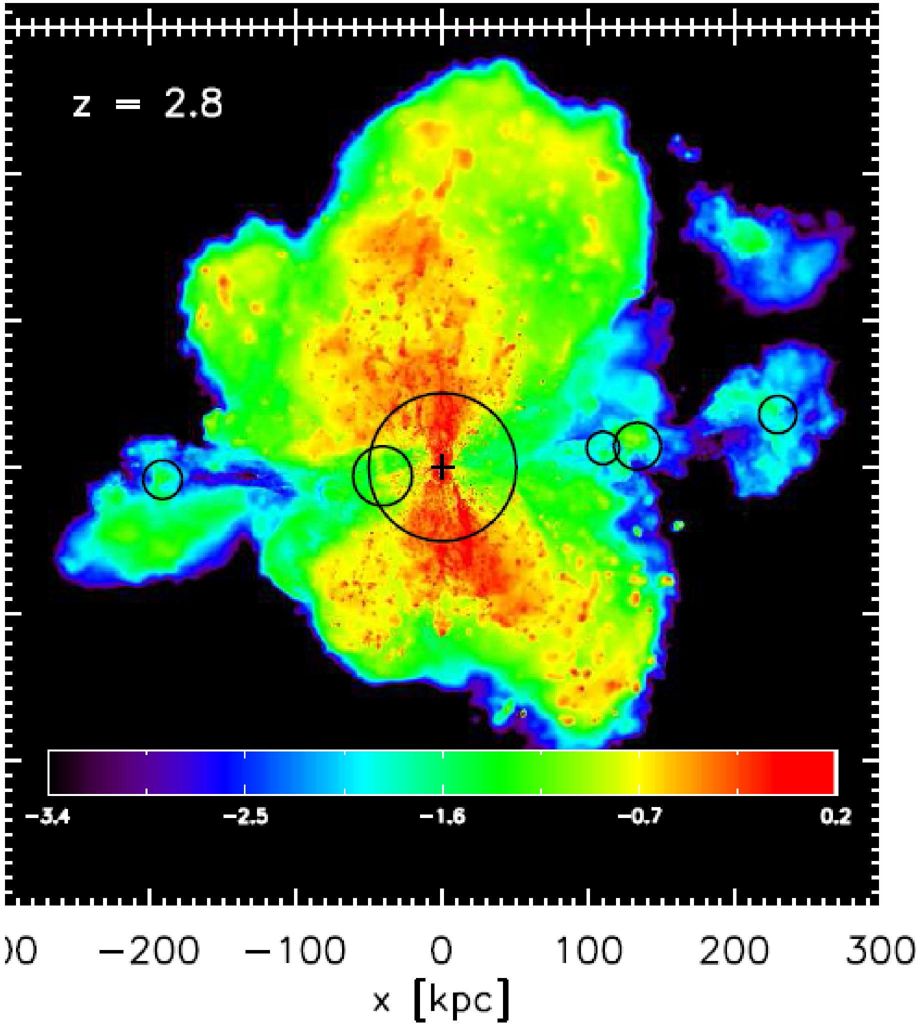
Starburst winds, the CGM, and the origin of coronal-phase gas



What happens when a wind flows into the CGM?

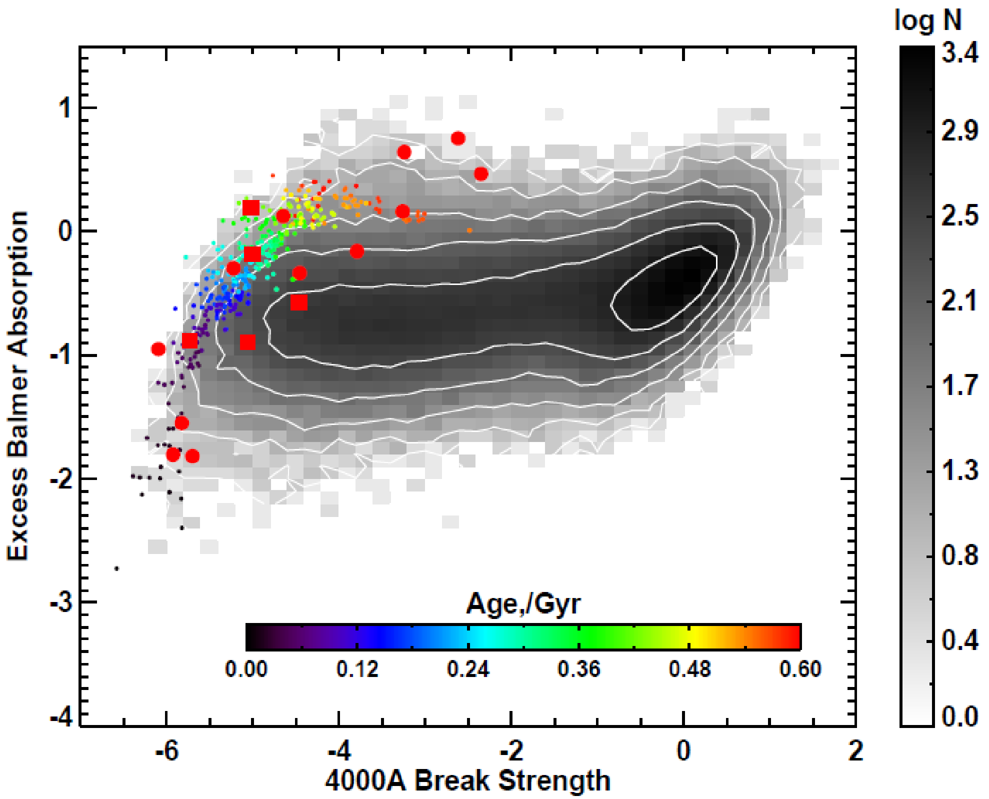
Test using QSO sightlines through the CGM of starbursts using COS

COS-Burst: Heckman, Borthakur, Wild, Schiminovich, & Bordoloi 2017



Compare to control sample of normal star-forming galaxies matched in M_* and impact parameter (ρ) observed with HST/COS

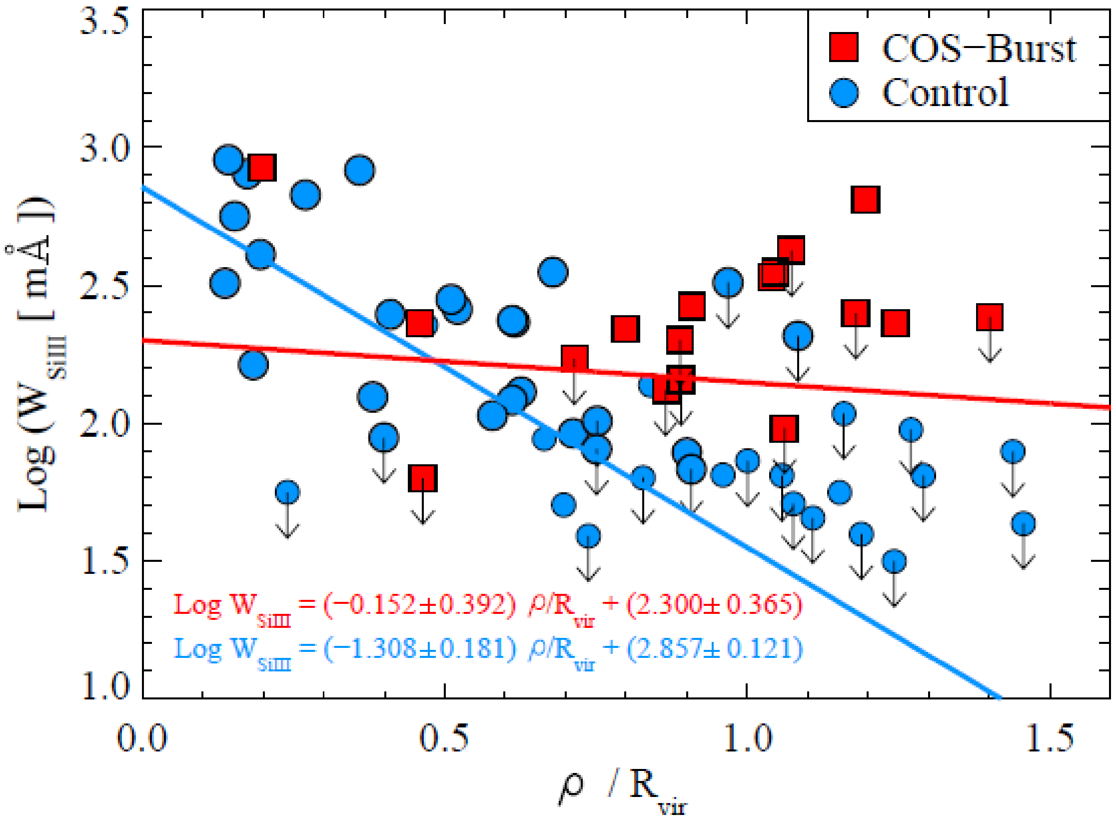
COS-Burst Sample

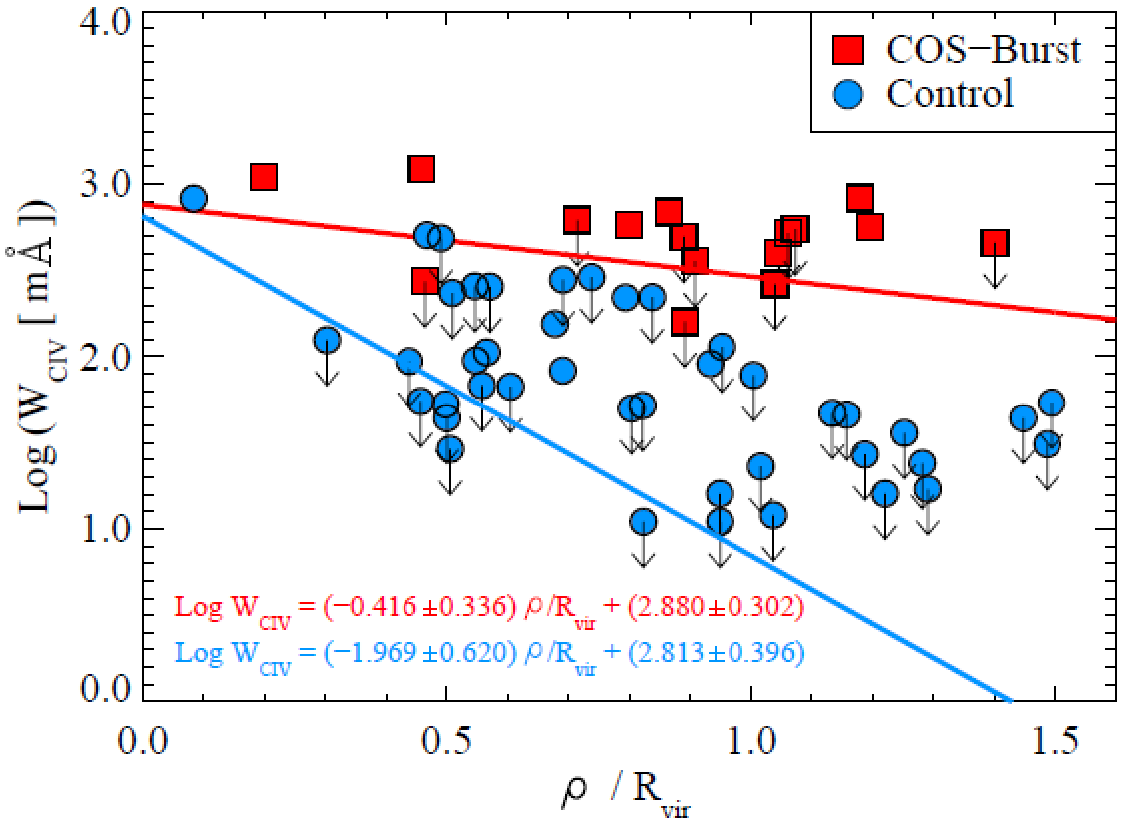


- Galaxies selected from SDSS legacy sample based on PCA approach
- 17 cases with suitable QSO
- Burst parameters derived from PCA vs. models plus Balmer emission-lines
- Median values given below
- Total supplied kinetic energy ~10^{59} ergs

$\log M_*$	v_c^b	R_{50}	R_{vir}	ρ	f_{burst}	t_{burst}	logsSFR	logSFR
Log $M_\odot$	km s^{-1}	(kpc	kpc	kpc		(Myr	(Log yr^{-1})	(log $M_\odot yr^{-1}$)
10.34	129	3.2	184	179	0.17	280	-9.24	1.07

Higher column densities of metals compared to the *outer* CGM of normal star-forming galaxies

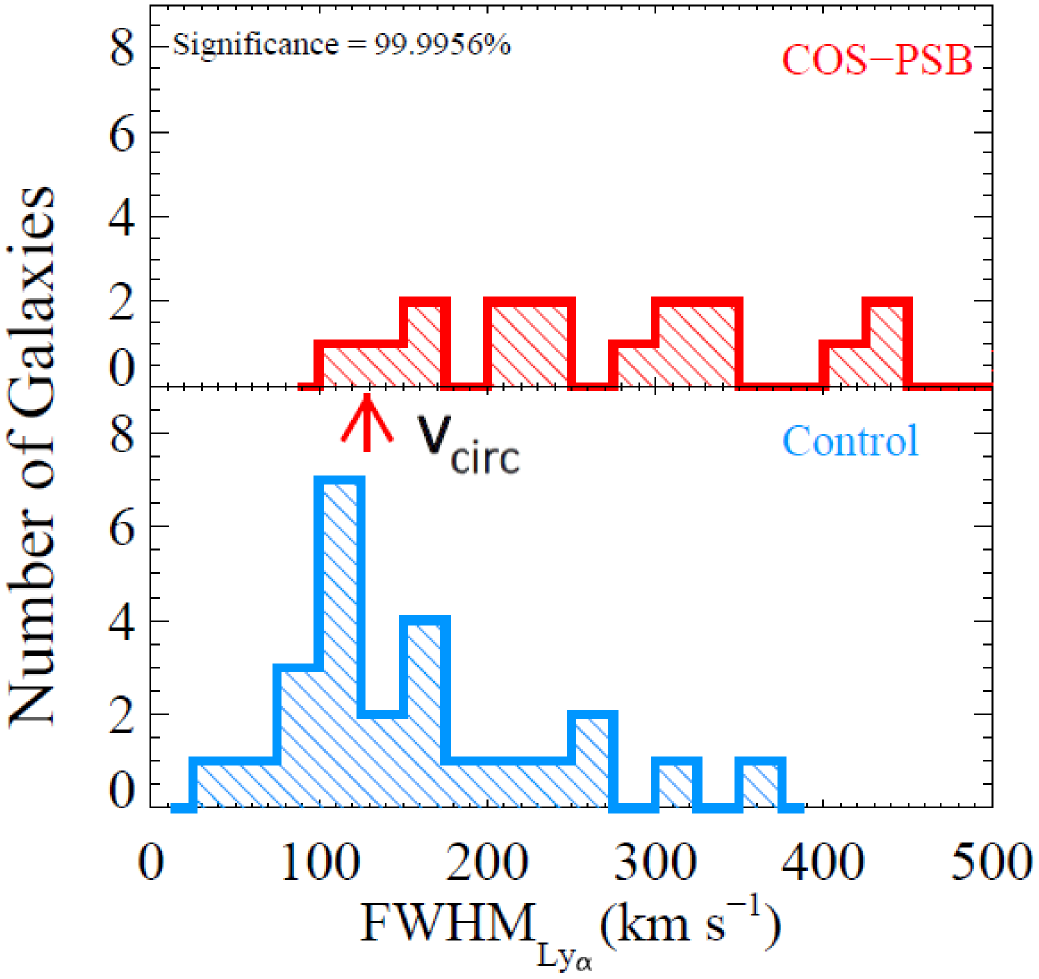


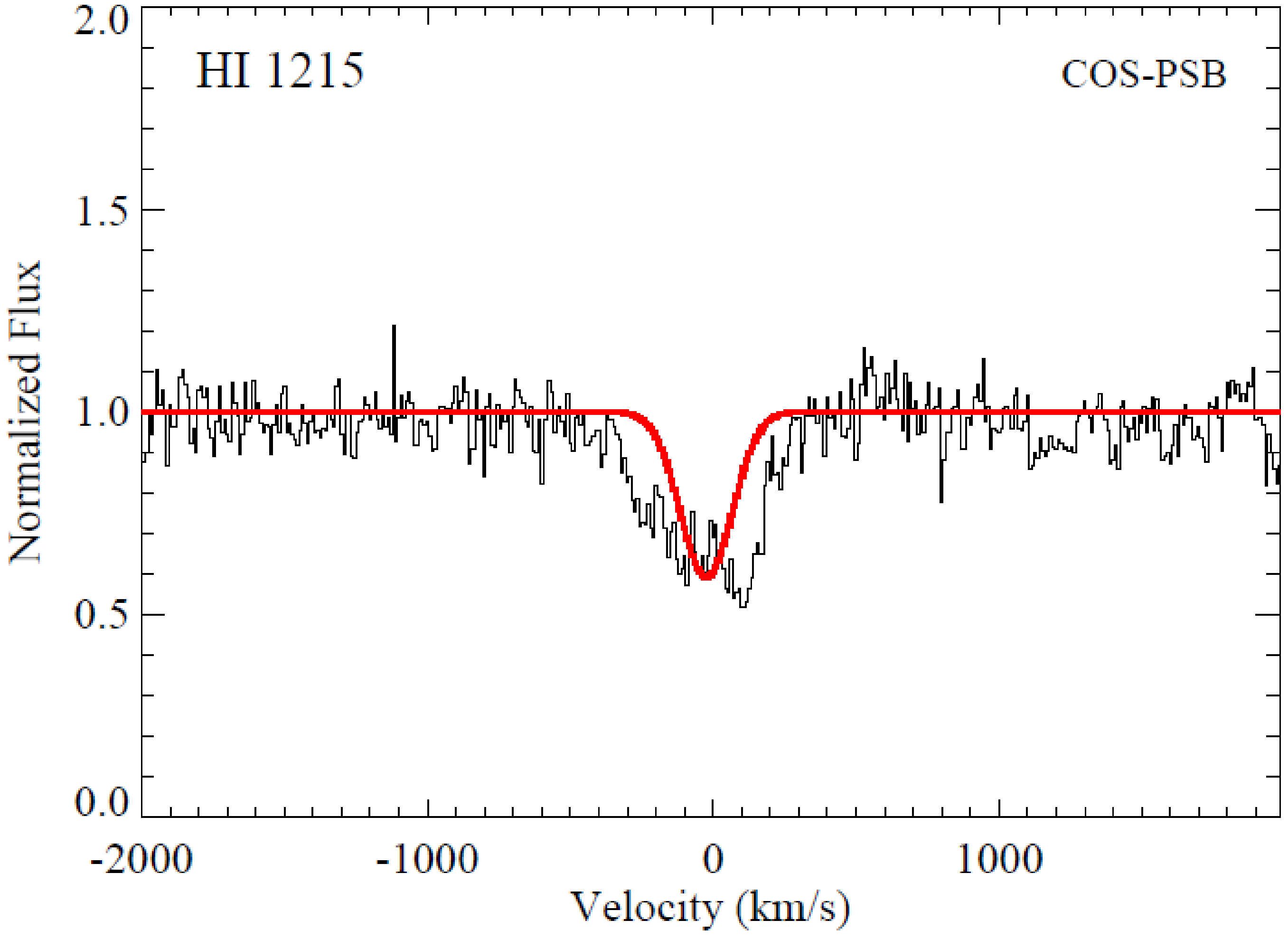


- Note that Si III and C IV lines have τ ~ 1, so that EQW traces column density
- Typical values are ~ few x 10^{13} and few x 10^{14} cm^{-2} respectively
- Covering factor ~ 50% in outer CGM

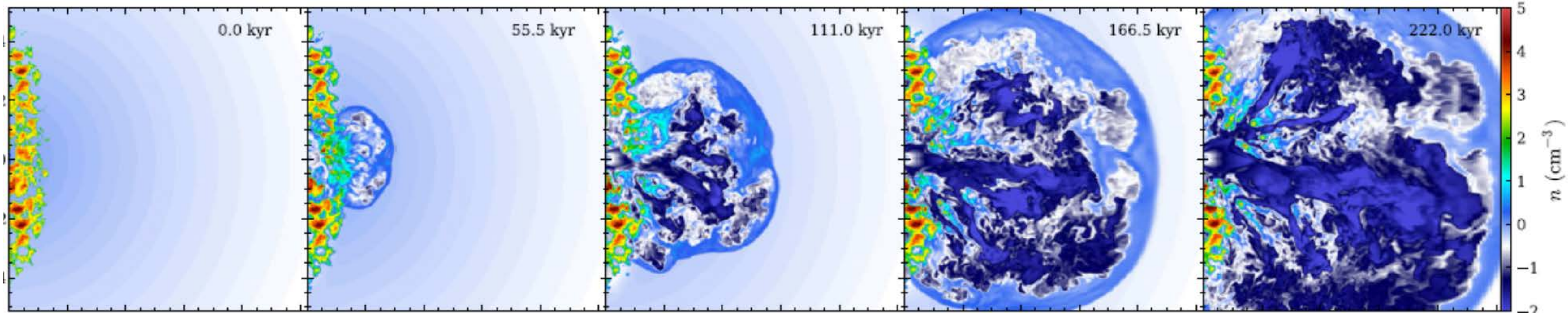
Super-virial velocities

$v_{cgm} \sim 2\ v_{vir}$ (FWHM ~ 425 km/s in stacked spectrum)





Interpretation



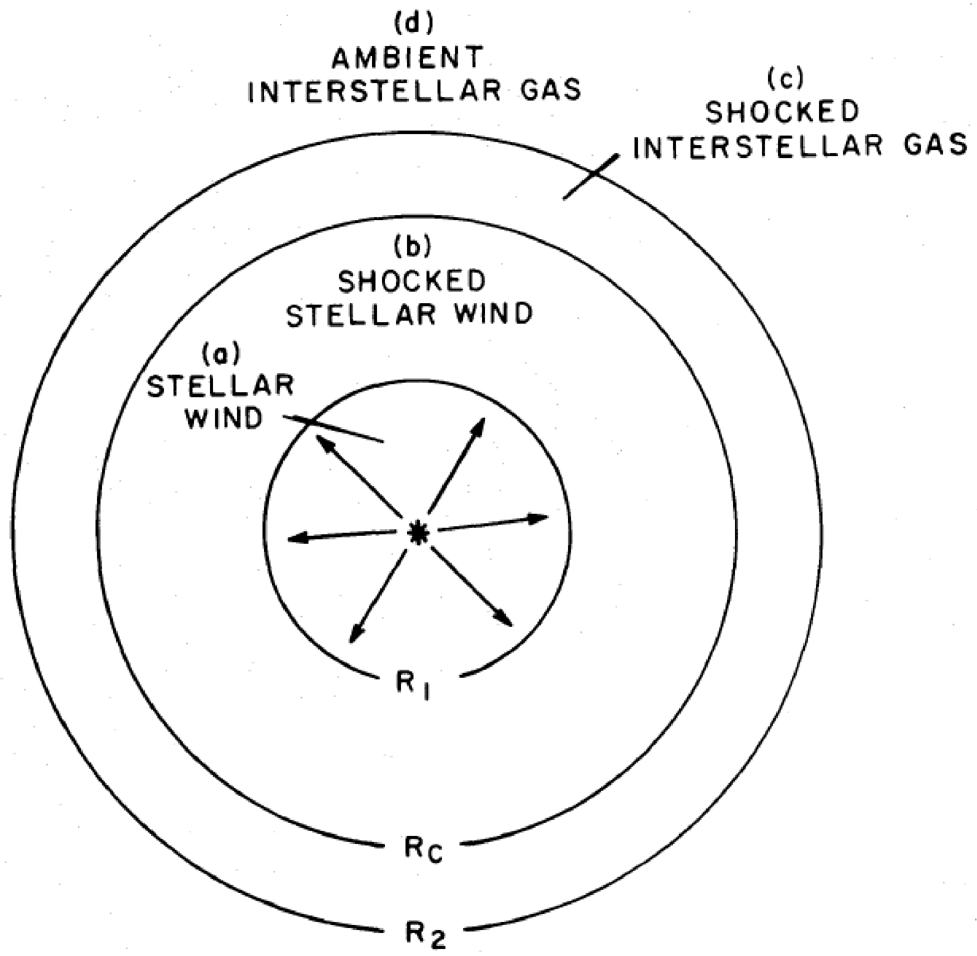
- Starburst-driven wind-fluid drives an expanding bubble (shock) out into a pre-existing multiphase CGM (clouds and volume-filling hot phase)
- This can accelerate (create?) clouds and drive the outflow of metals

Can the wind fluid reach the outer CGM?

- Consider classic wind-blown bubble expanding into the CGM (Weaver + 1977)
- Volume-filling phase has a total mass 10^{10} $M_{\odot}$ and $\rho \propto r^{-1}$ (cf. Miller & Bregman; Voit; Das)
- Adopt the mean starburst age of ~300 Myr
- Mean energy injection rate is ~10^{43} erg/s
- Similarity solutions (cf. Dyson 1989)
- Energy-driven case:

  $R_{bubble} \sim 195 \; dE/dt_{43}^{1/4} \; M_{hot,10}^{-1/4} \; t_{300}^{3/4}$ kpc
- For momentum-driven case, get:

  $R_{bubble} \sim 170 \; dp/dt_{34.7}^{1/3} \; M_{hot,10}^{-1/3} \; t_{300}^{2/3}$ kpc



Summary #1

- ***The CGM differs significantly in low-z galaxies that have recently undergone a starburst compared to normal star-forming galaxies:***

  Higher column densities of metal ions (C IV and Si III)

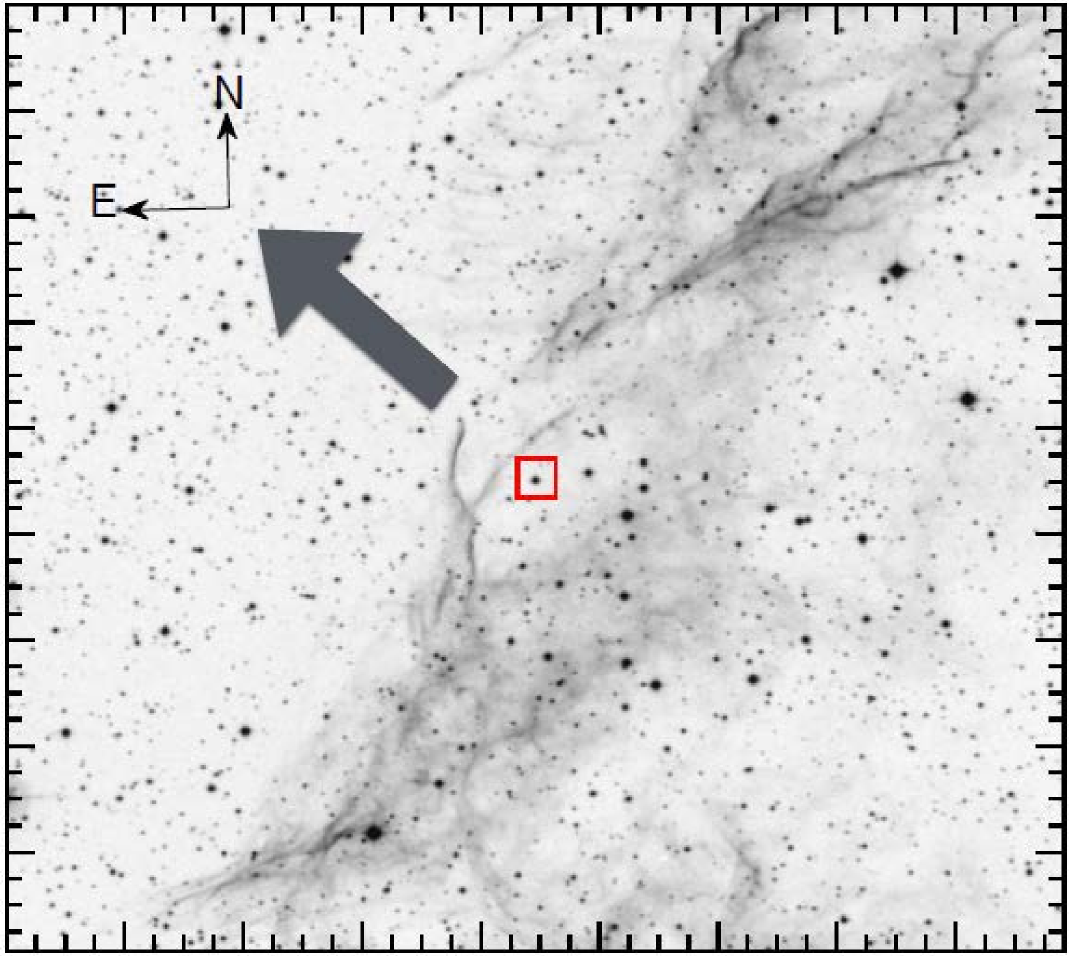
  Higher velocity dispersions (velocities well in excess of v_{circ})

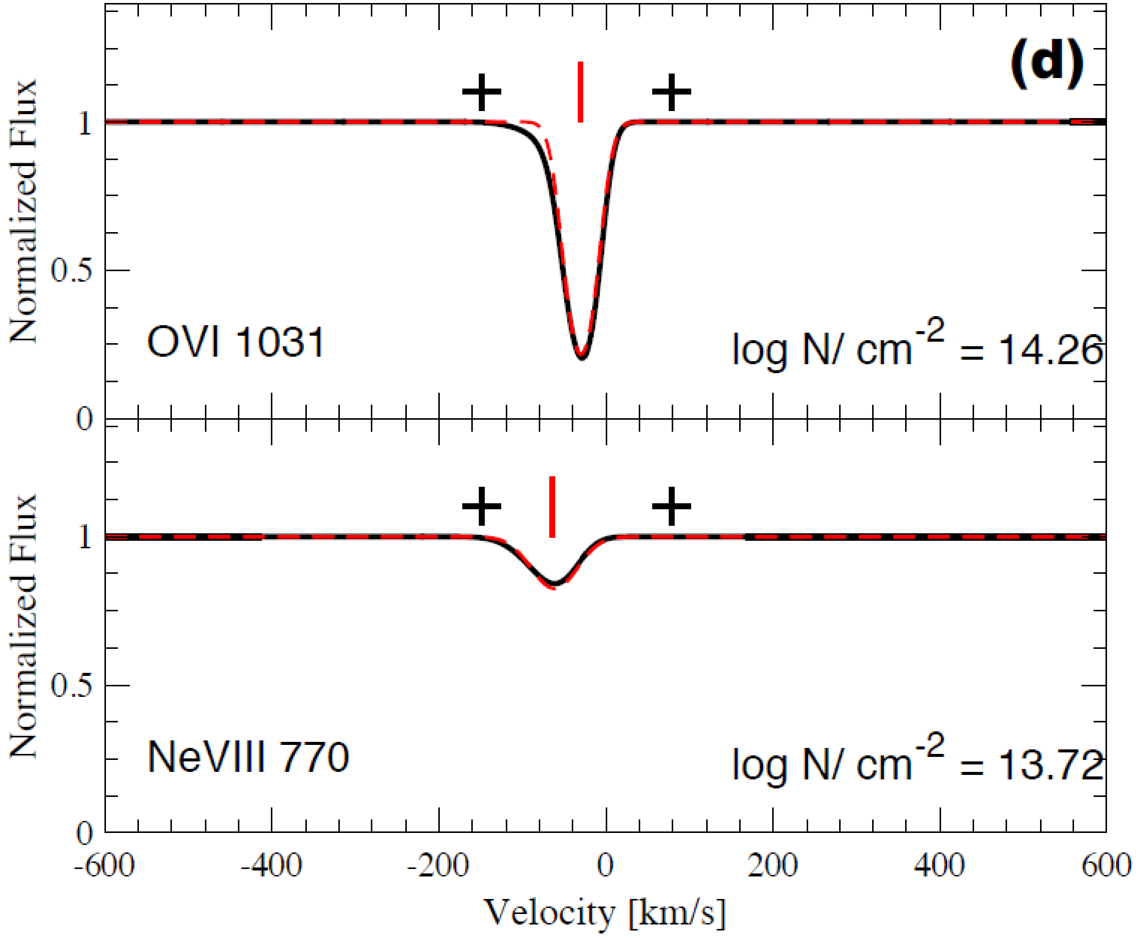
- ***These properties reflect the interaction between a starburst-driven wind and a pre-existing CGM. This interaction extends to the virial radius***
- ***Key new observational input to simulations of galactic winds***
- ***Provides a new probe of the low-z CGM in typical galaxies***

Bonus Coverage: Coronal Gas in the CGM

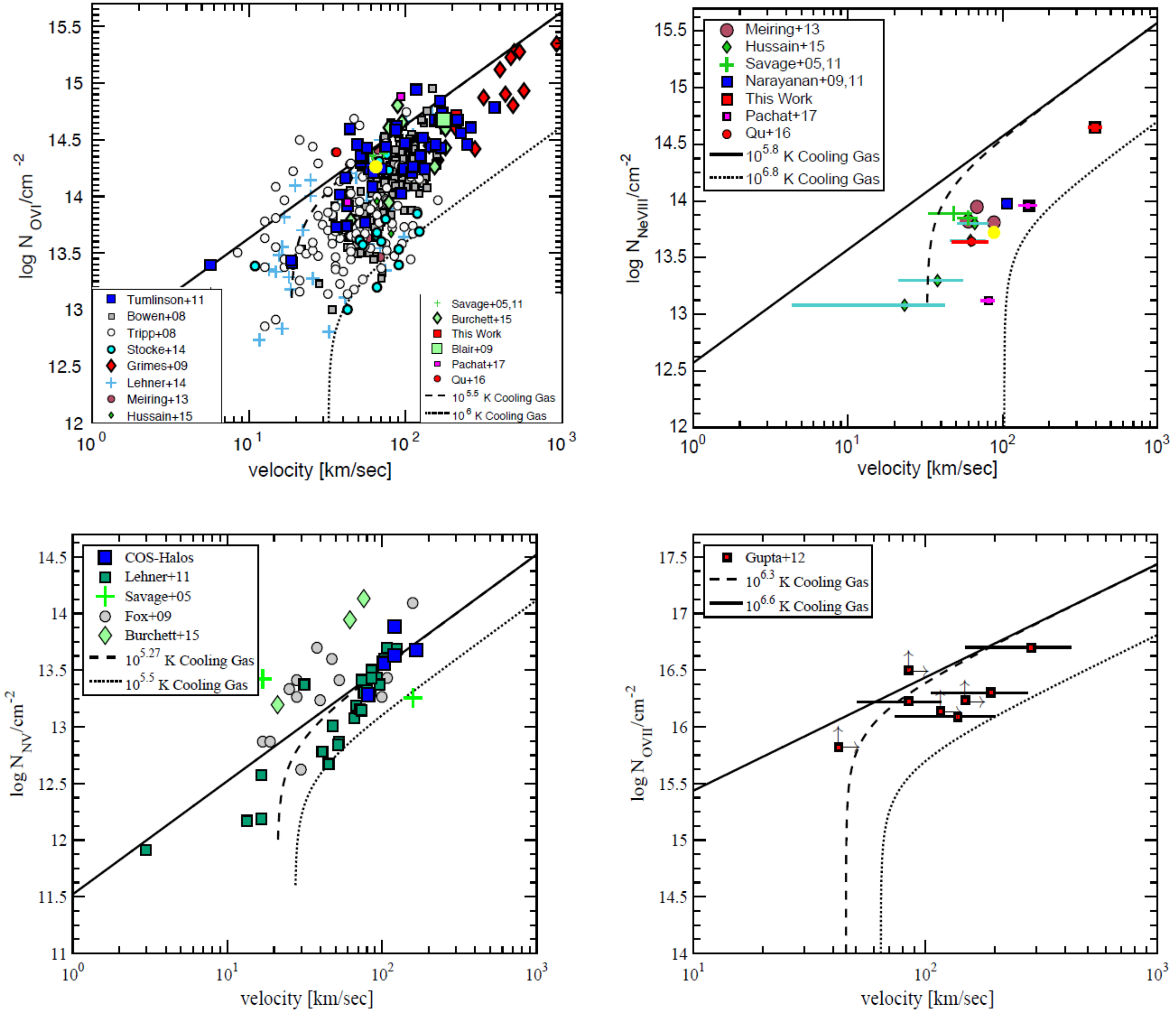
- Simple model of radiatively-cooling gas-flow (Heckman+02 and Bordoloi+17)
- $N_{cool} = n\ L_{cool} = n\ t_{cool}\ v_{cool}$
- For radiatively cooling gas flow $t_{cool} = 3kT/n\Lambda$, where $\Lambda(T,Z)$ is the cooling function
- $N_{cool} = (3kT/\Lambda)\ v_{cool}$ independent of density (n)
- For some specific ion X,i: $N_{X,i} = (3kT/\Lambda)\ v_{cool}\ (X/H)\ f_{X,i}$, where $f_{X,i}(T)$ is the ionic fraction
- Since $\Lambda\ \alpha\ Z$ in coronal T-range, $N_{X,i}\ \alpha\ v_{cool}\ [T\ f_X(T)/\Lambda(T)]$, independent of n and Z
- Simple analytic arguments: $\Delta v \sim v_{cool}$, where Δv is the LOS line-width
- Have shown this explicitly using radiative shock models
- "Natural" value for T is near the value where $f_{X,i}$ peaks (T_{peak})
- BOTTOM LINE: EXPECT RELATIONSHIP BETWEEN COLUMN DENSITY AND LINE WIDTH, WITH MODEST DEPENDENCE ON TEMPERATURE NEAR T_{peak}

Sanity-check using data on the Cygnus Loop and from numerical shock models

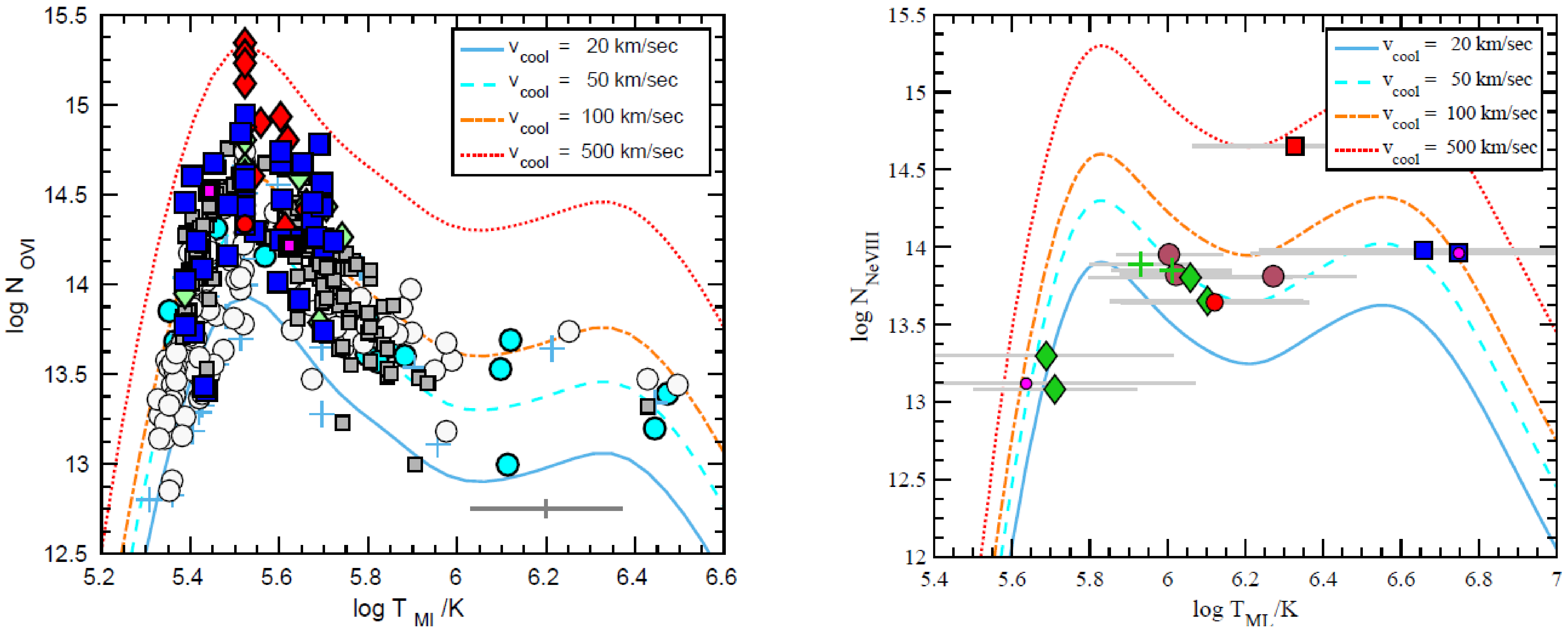




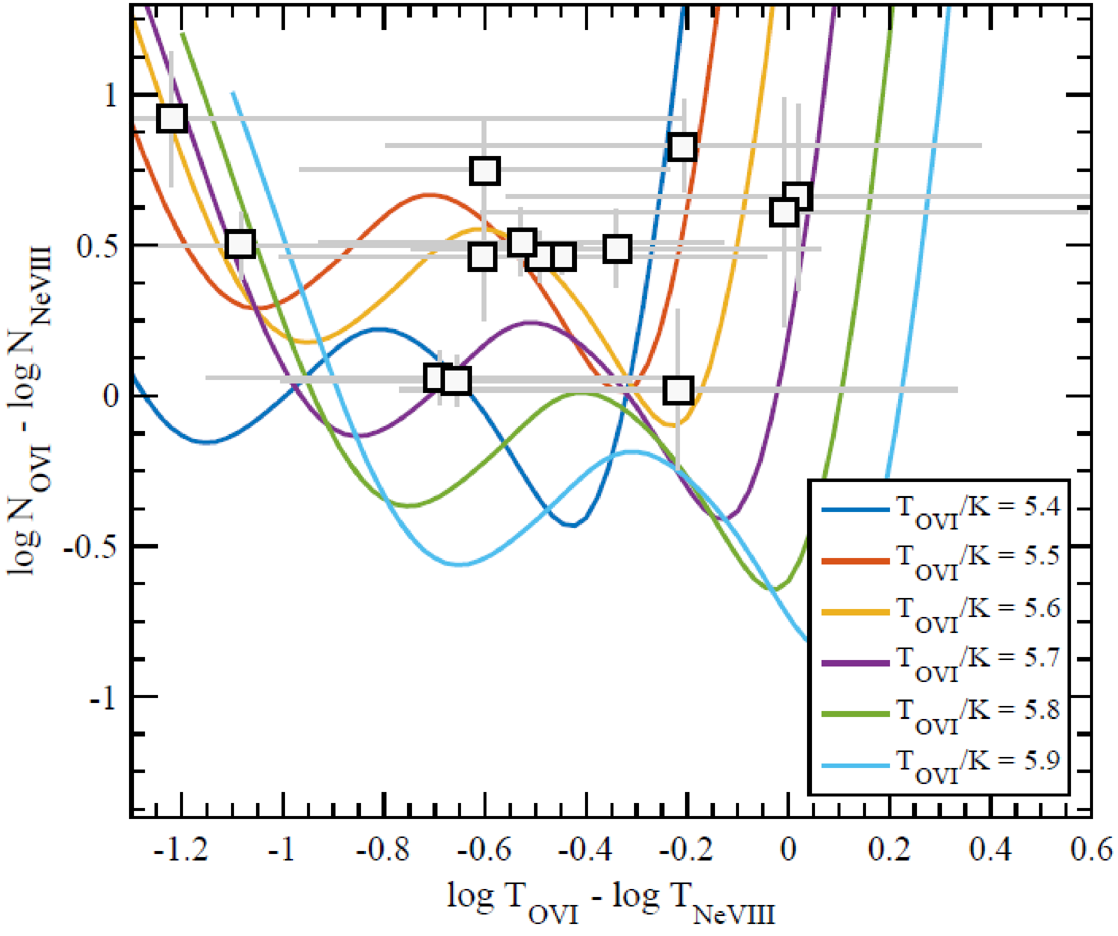
Results: model agrees with data for variety of systems and a range of high-ions

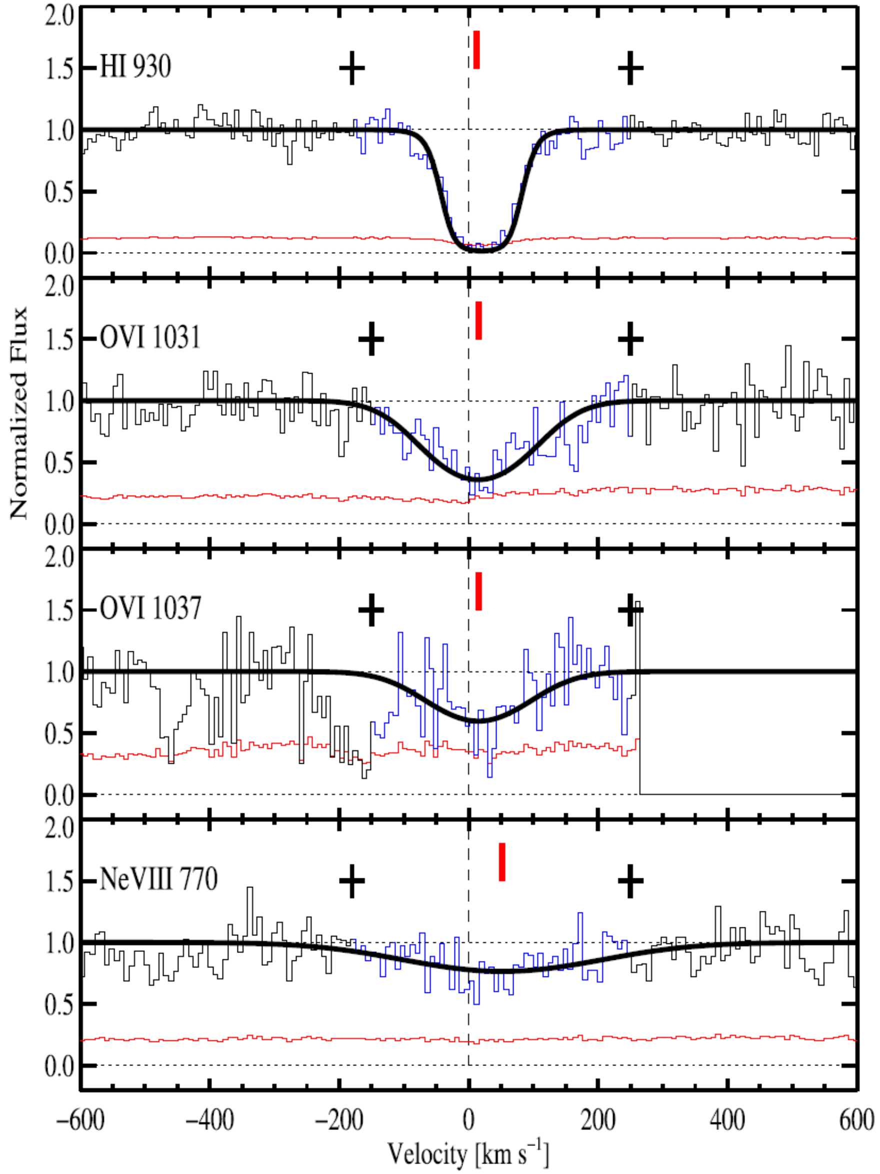


Inferred T clusters around T_{peak} for O VI



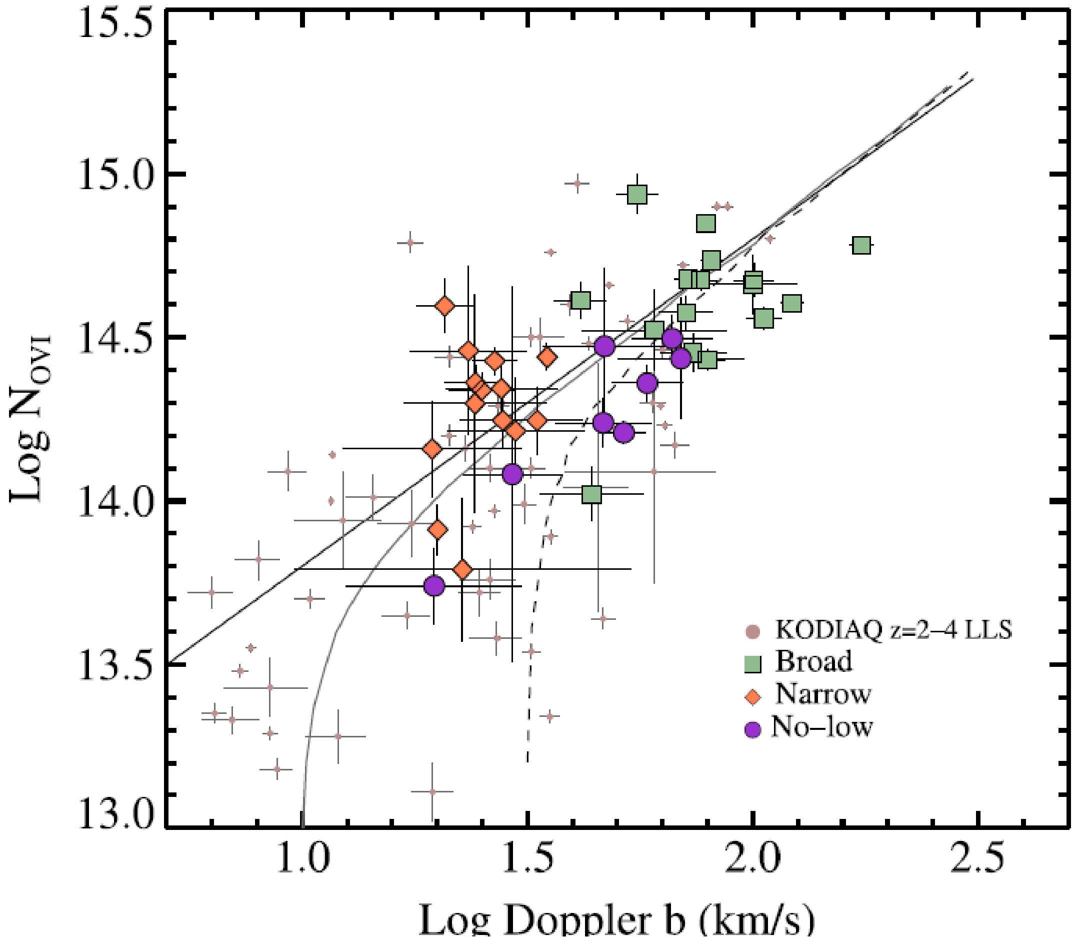
Model agrees with properties of O VI and Ne VIII when both are observed on the same LOS

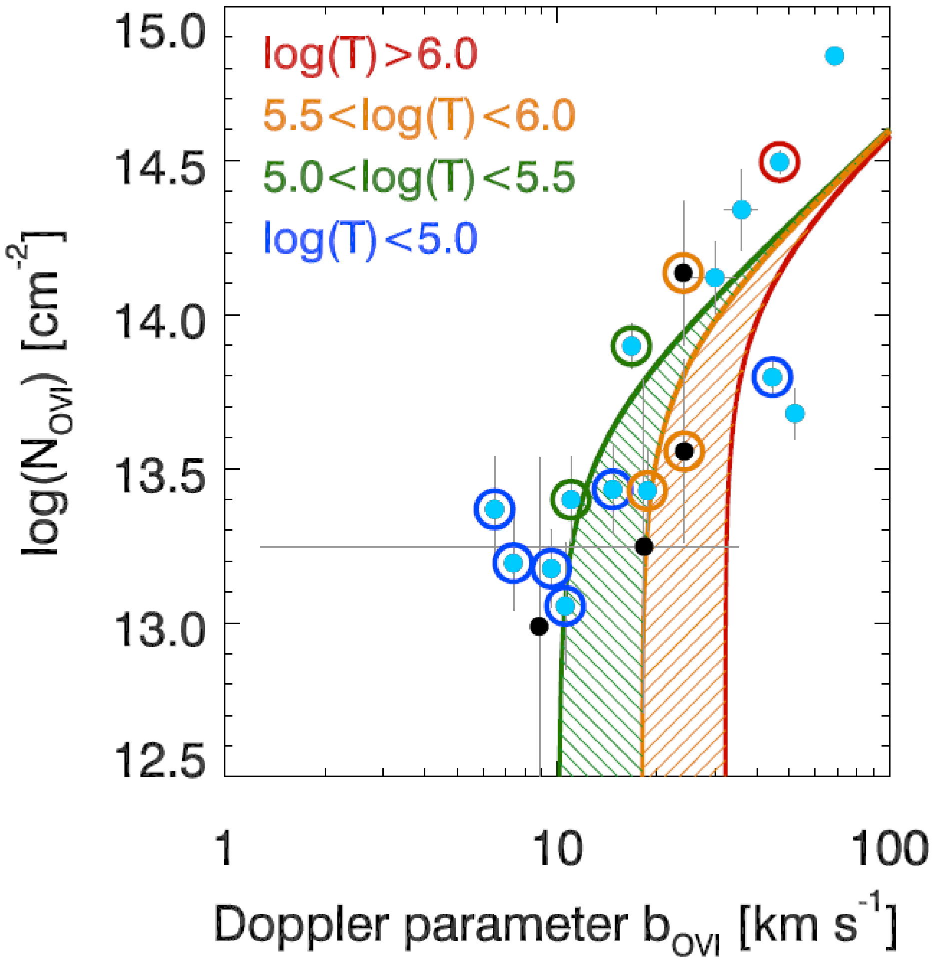




Consistent with CGM at z ~ 0 to 4

(Werk+16; Rudie+19)





Summary #2

- A simple model of a radiatively-cooling gas-flow can naturally account for the properties of coronal-phase gas in the CGM (and elsewhere)
- Successfully predicts the relationship between column density and line-width
- Successfully predicts the different column densities and widths seen in N V, O VI, NeVIII, and O VII(?) lines
- The model has only one free parameter, the column-density-weighted mean temperature for the observed ion, and this is highly constrained to be in the temperature range at which the ionic fraction is significant
- Could apply to shocks, turbulent mixing layers, cooling winds, etc.
- Occam's Razor