Metal-Enriched Galactic Outflows and their impact on the CGM

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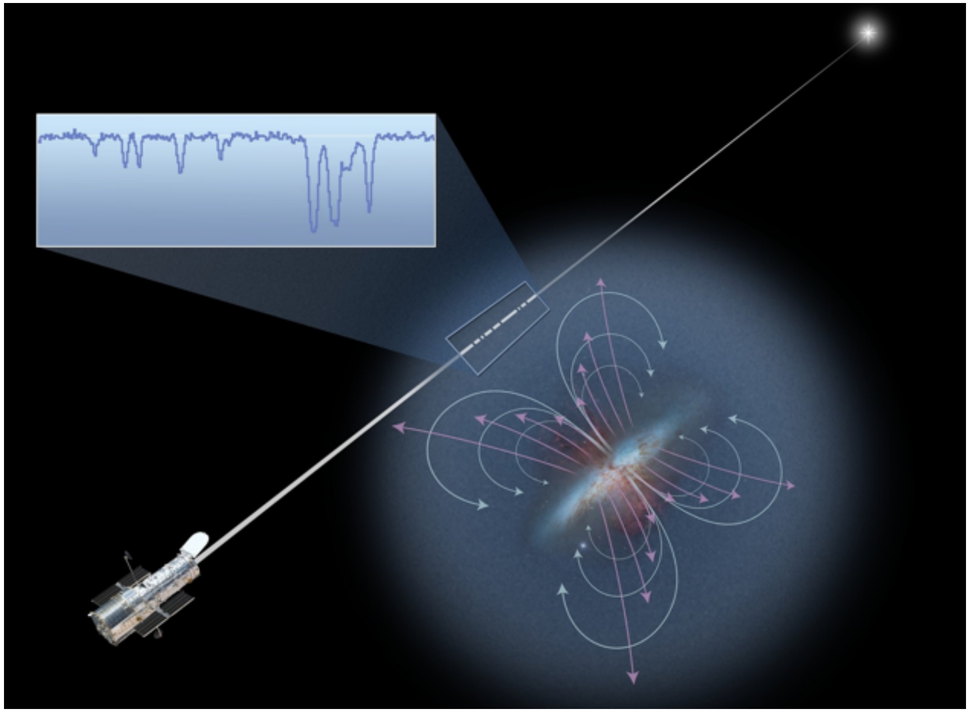
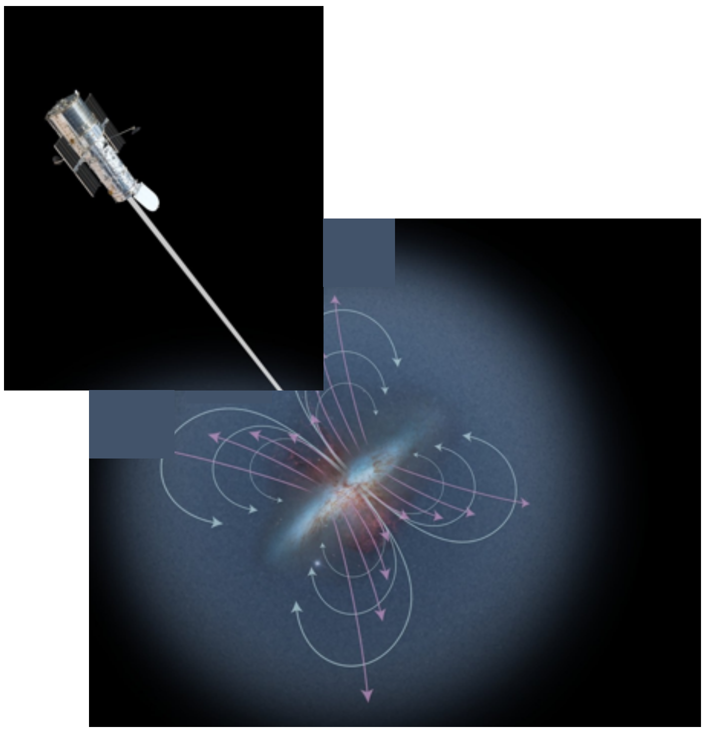
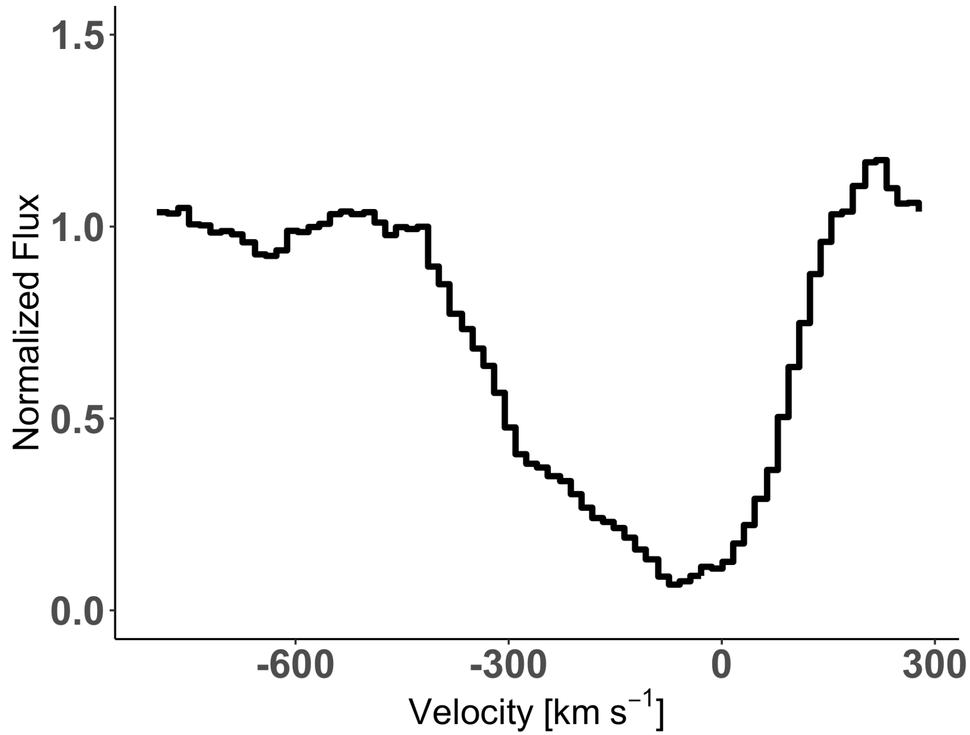
with Christy Tremonti and Claus Leitherer

Can observed outflows explain the massive CGM?



Down-the-barrel absorption lines use background starlight to measure the column density and velocity of outflowing gas





See also: Heckman+ 2000 Rupke+ 2005, Martin 2005, Tremonti+ 2007, Steidel+ 2010, Martin+ 2012, Rubin+ 2014, Heckman+ 2015

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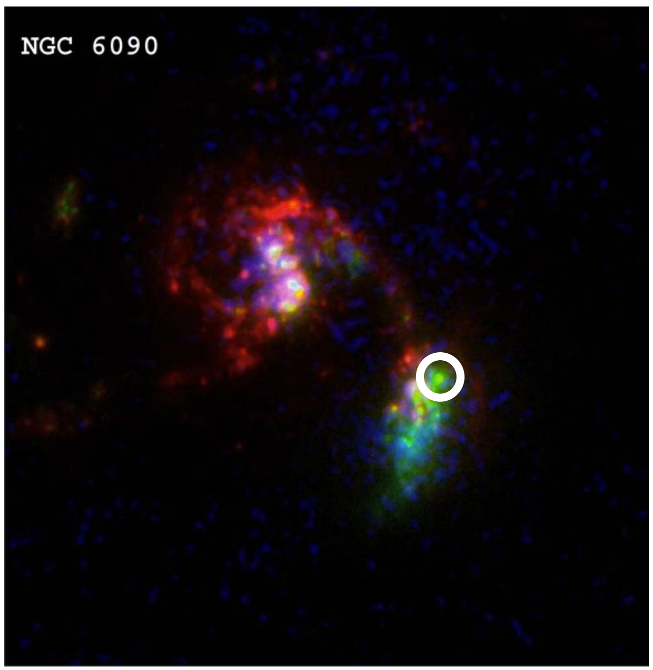
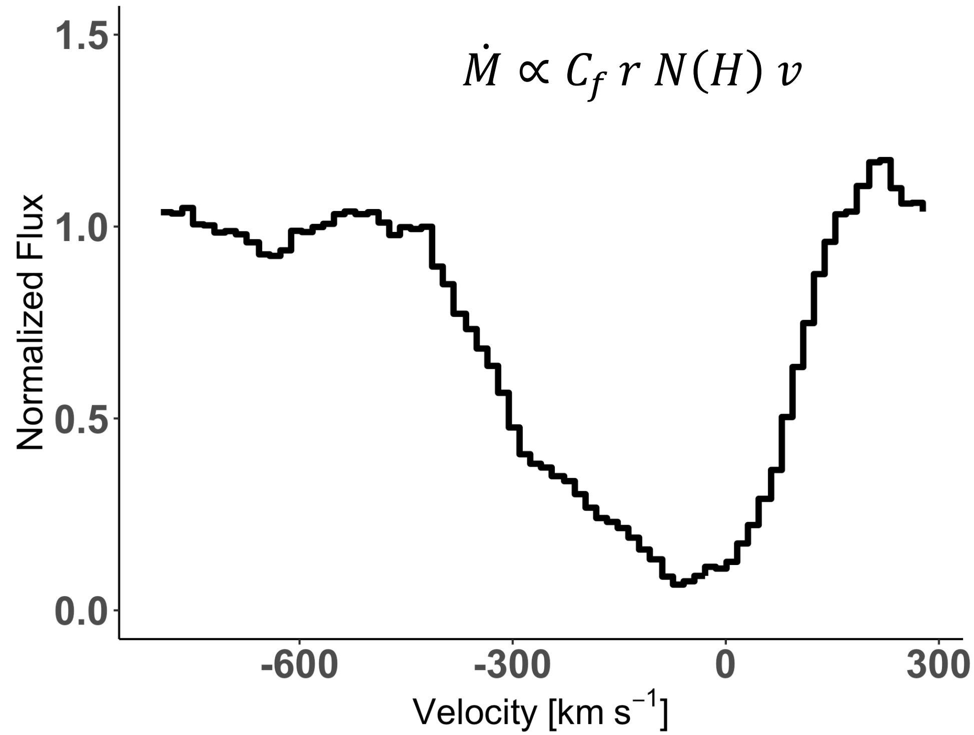
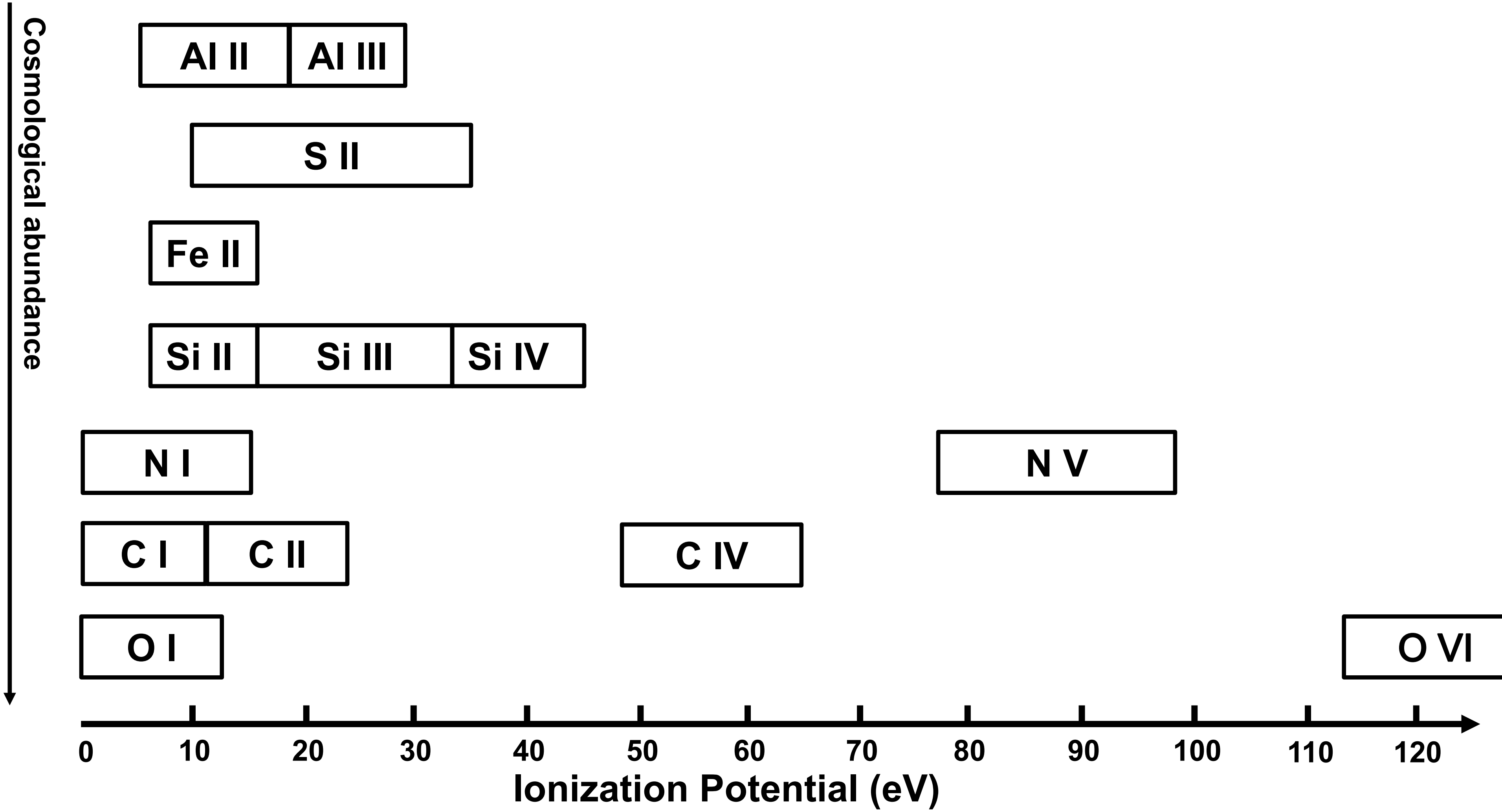


Blue: Lyα, Red: Hα, Green: UV continuum
(Östlin+ 2009)

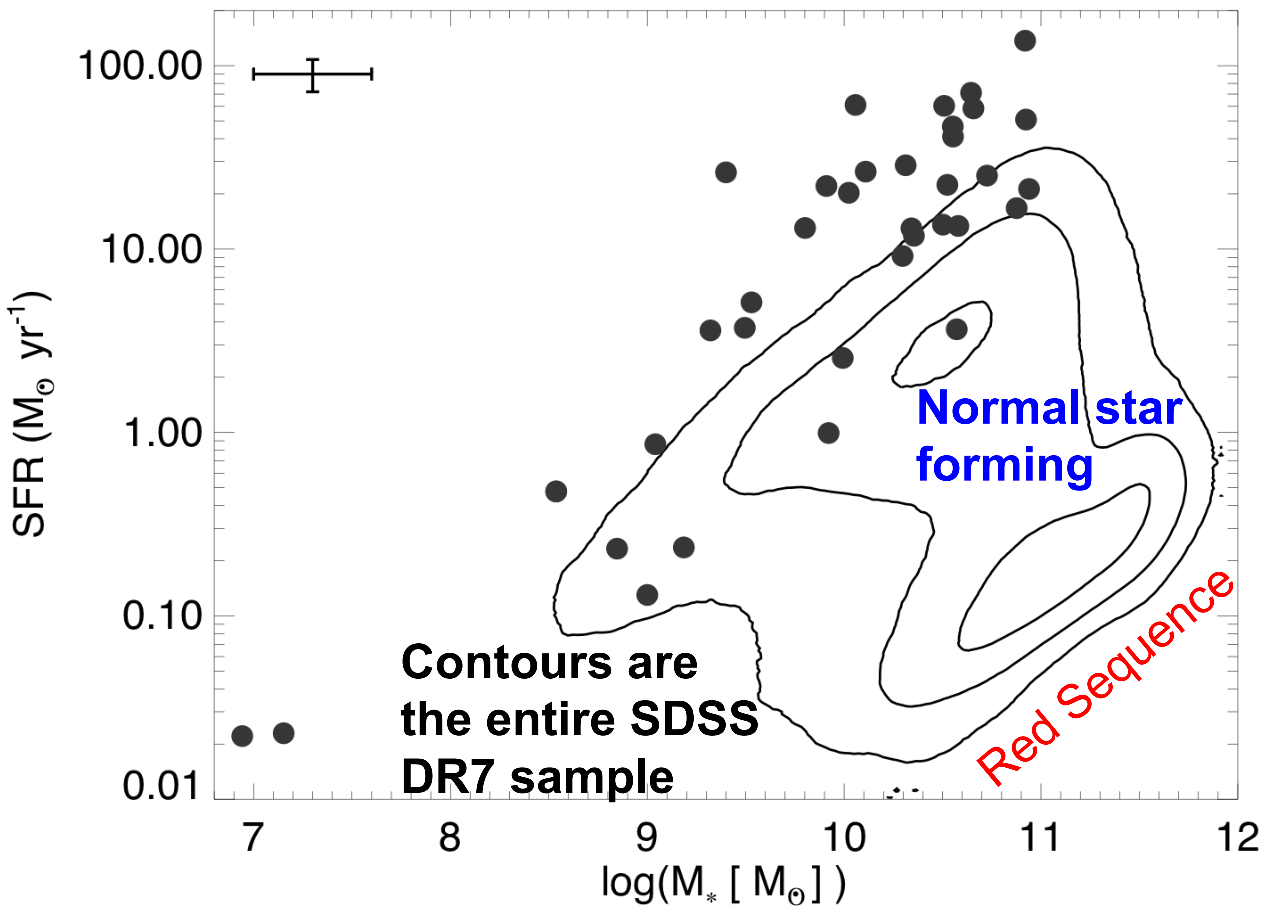


See also: Weiner+ 2009, Steidel+ 2010, Martin+ 2012, Rubin+ 2014, Heckman+ 2015

Strong absorption lines observed in the far-ultraviolet cover a wide range of ionization potentials



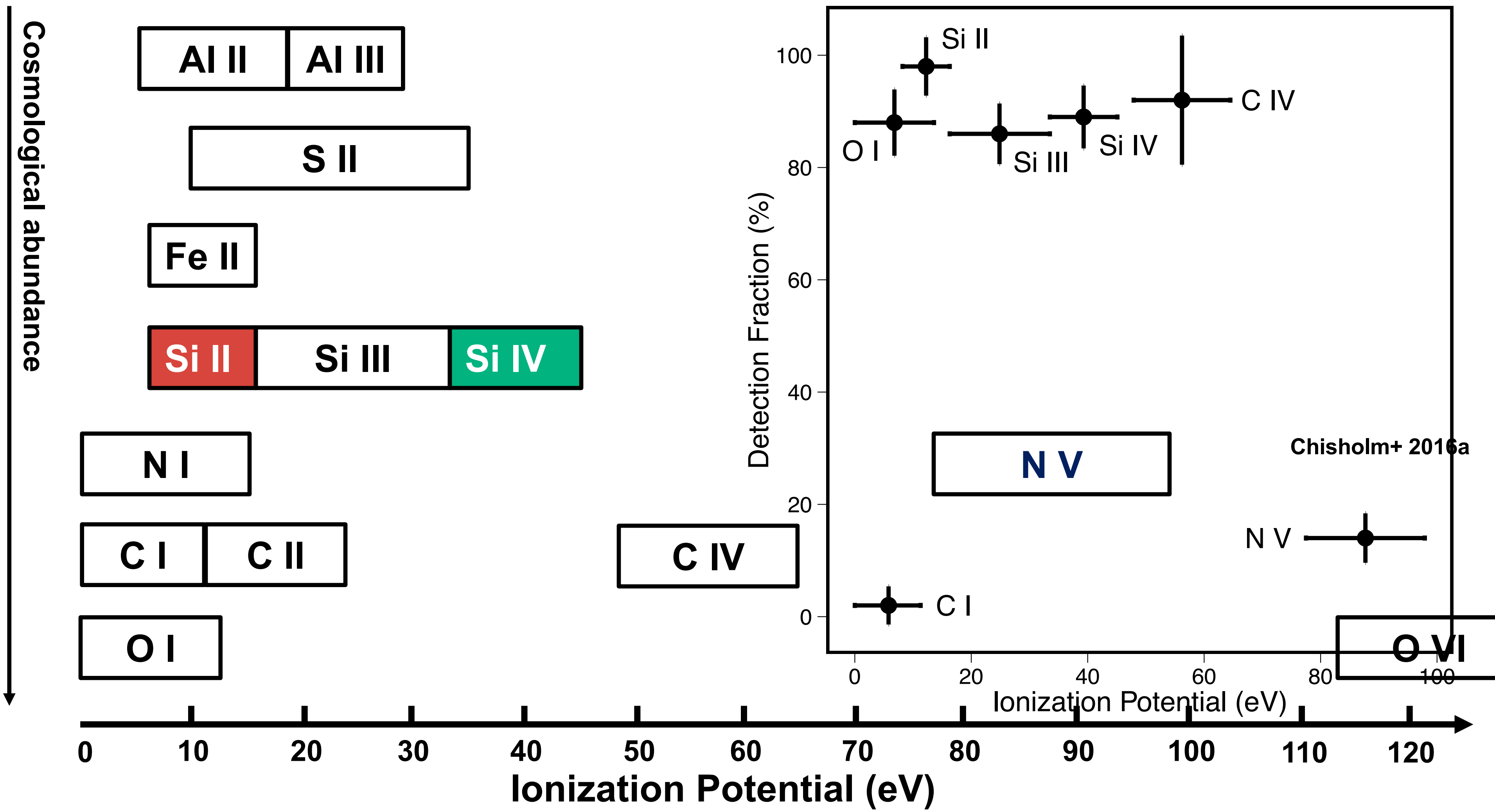
The HST archive sample spans a large range of host galaxy properties



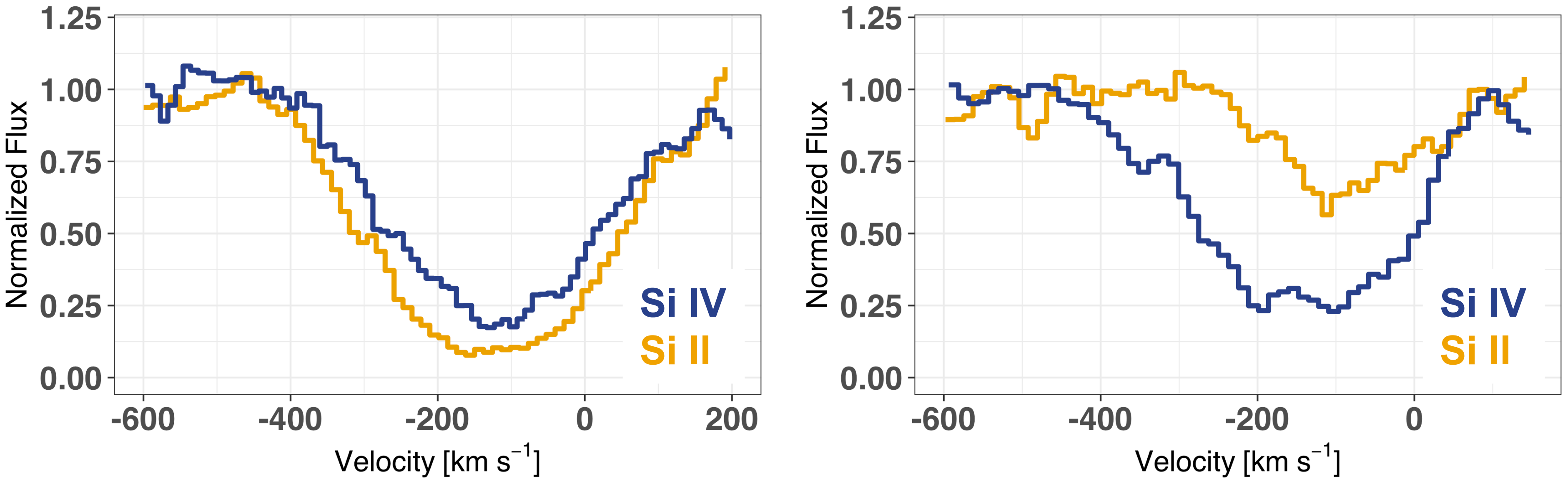
Chisholm+ 2015

37 HST/COS observations of local star-forming galaxies, but only 7 at very high signal-to-noise

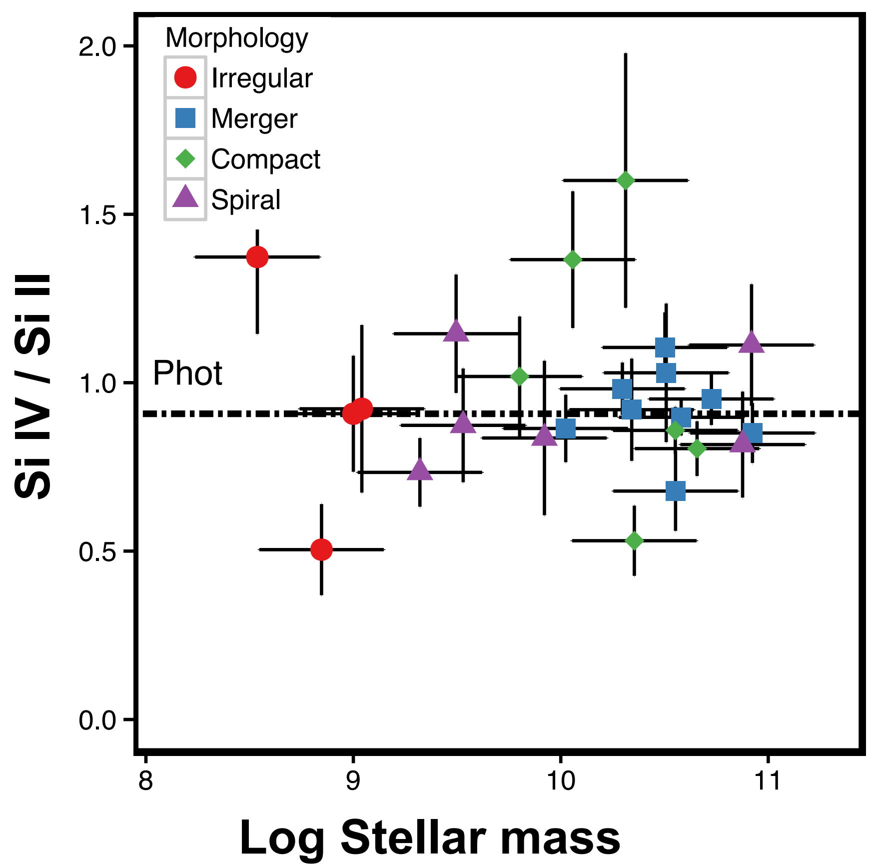
The presence and strength of the different absorption lines trace the outflow ionization structure



The outflow ionization state sets the ratio of different FUV absorption lines



The ratio of UV lines determines the ionization of the outflows



Chisholm+ 2016a

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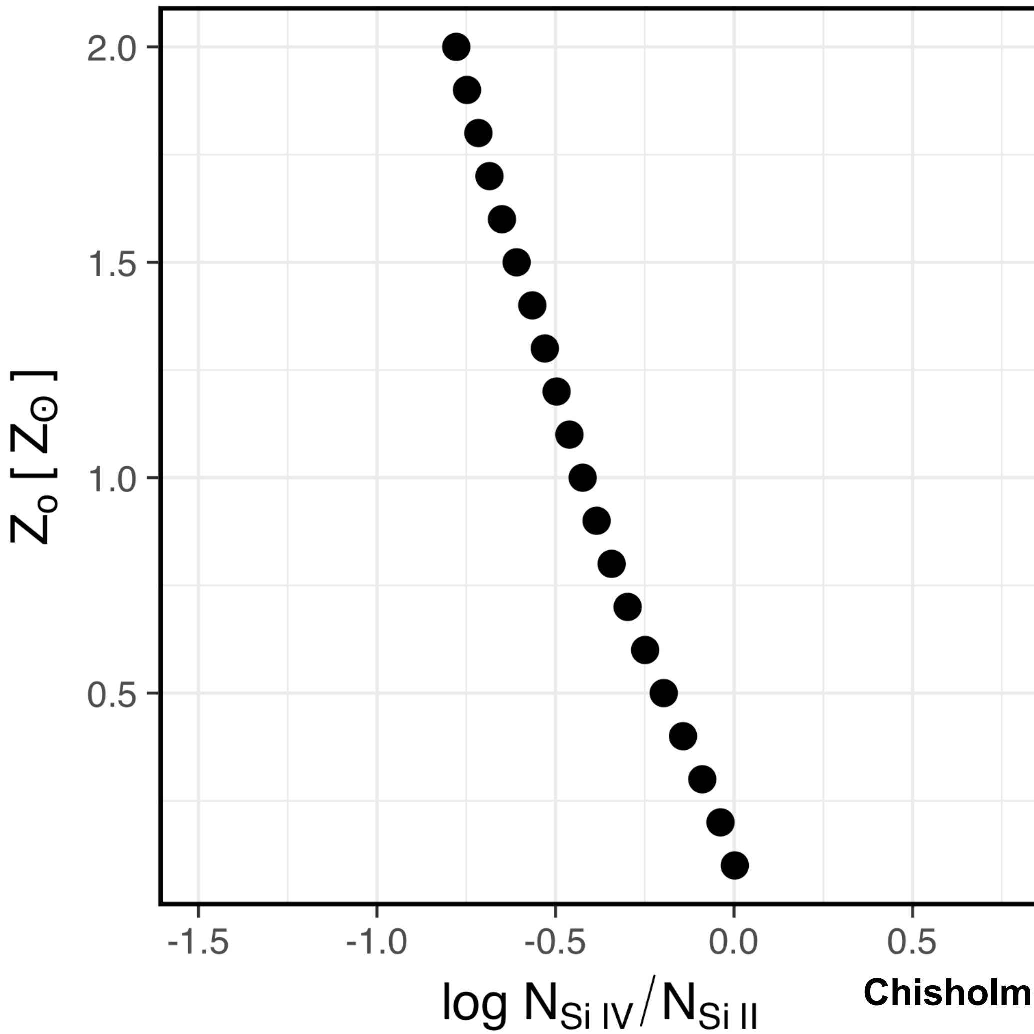

Chisholm+ 2018

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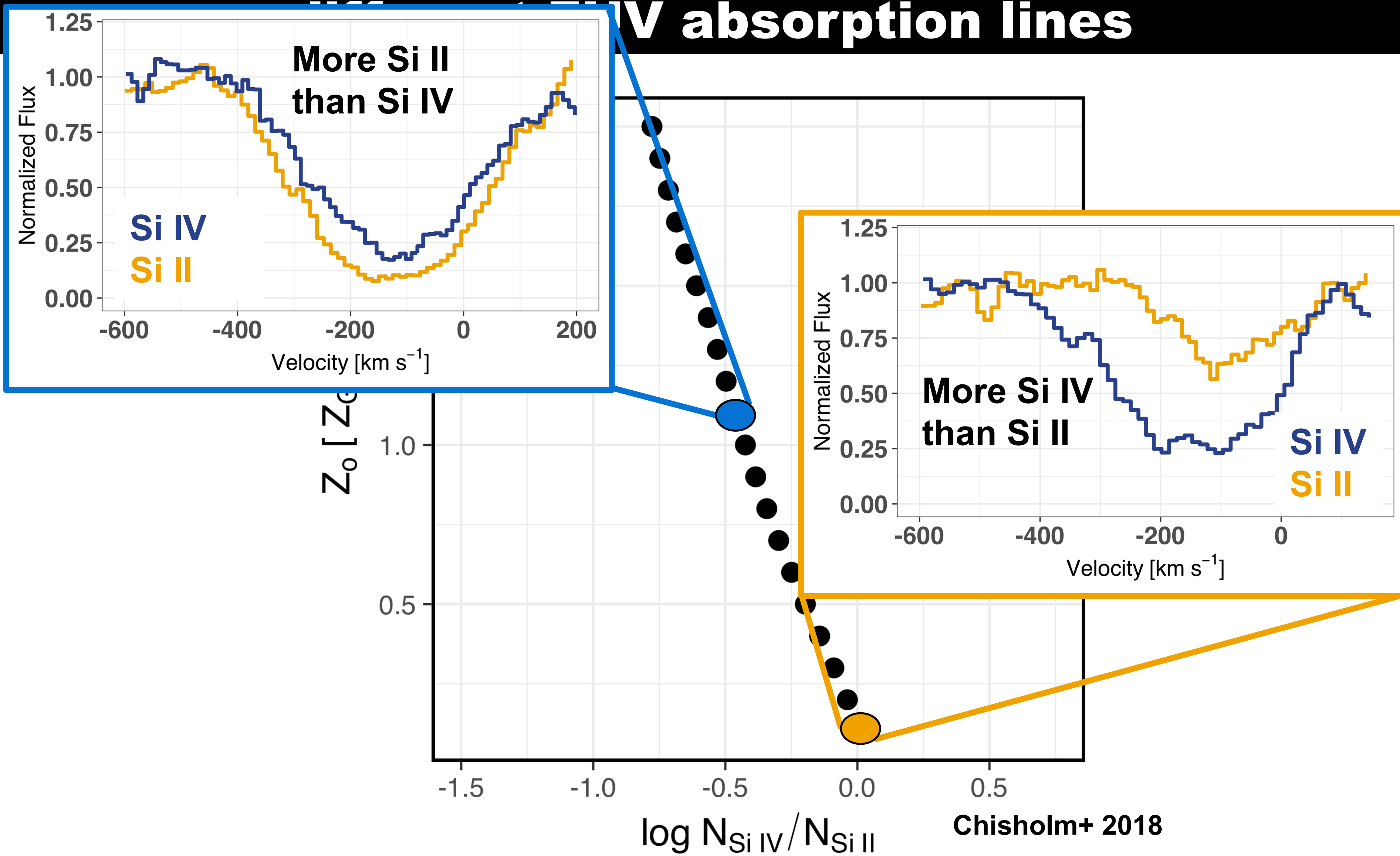
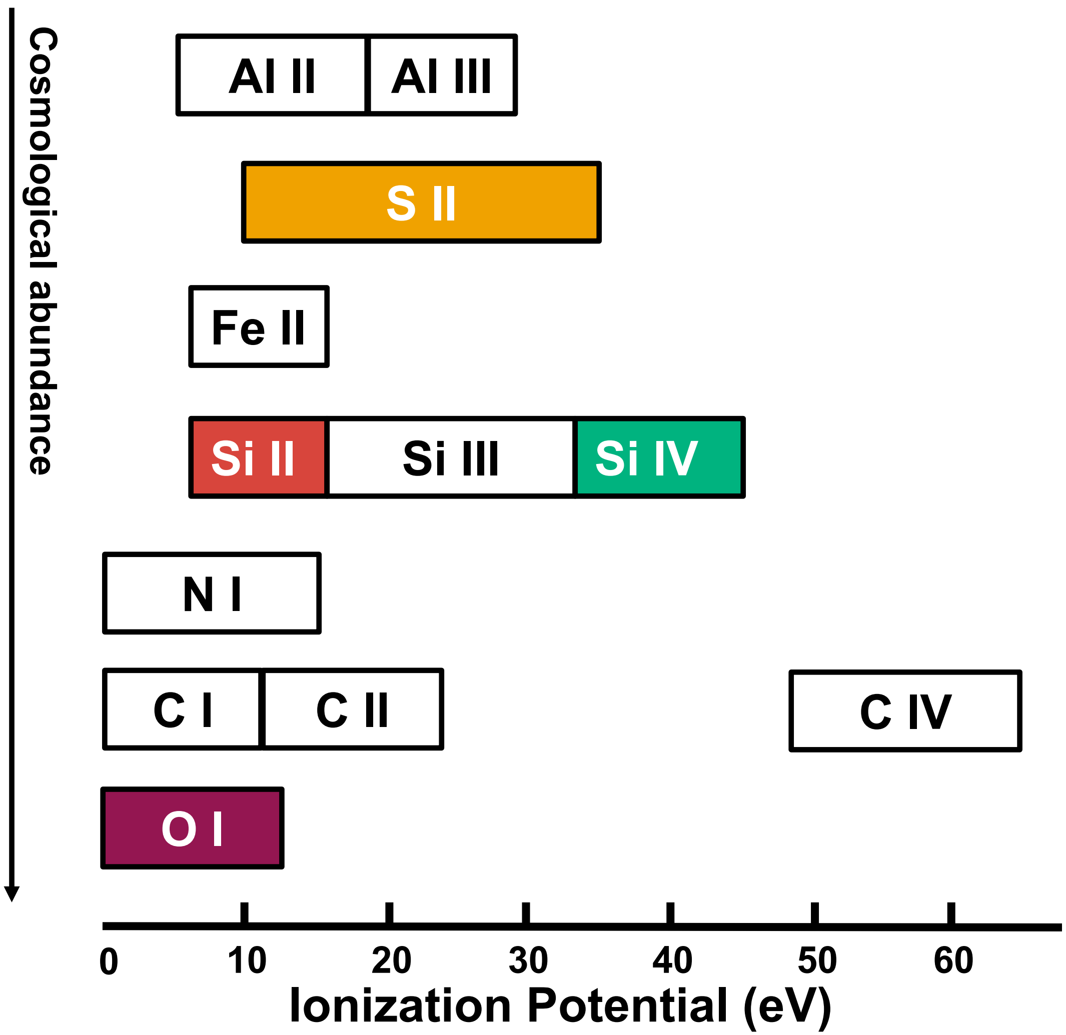
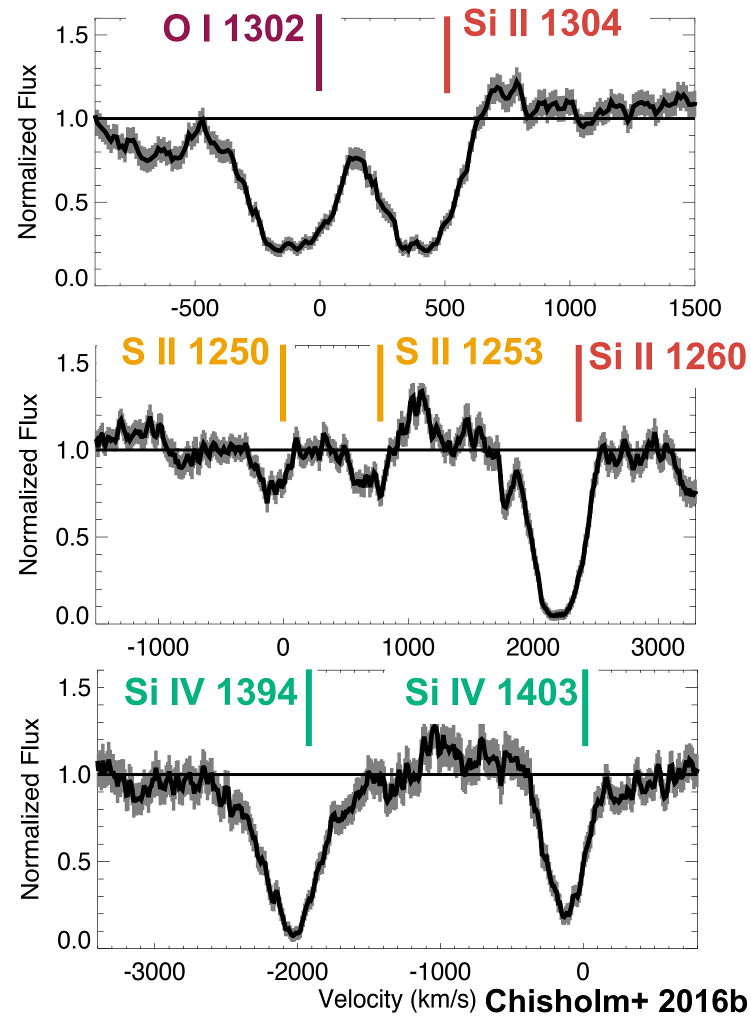


A Bayesian method uses the observed absorption lines and Cloudy models





Chisholm+ 2016b

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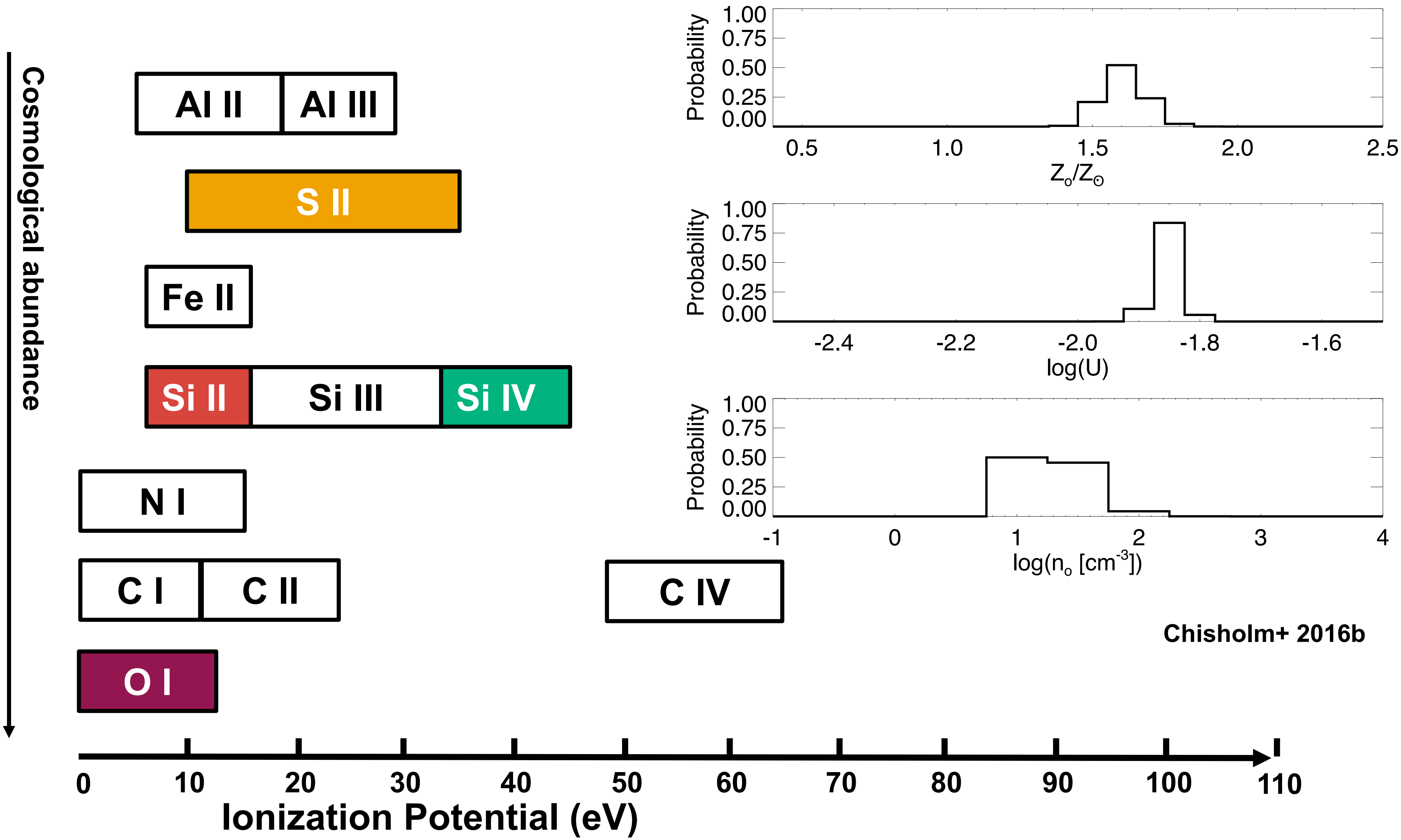
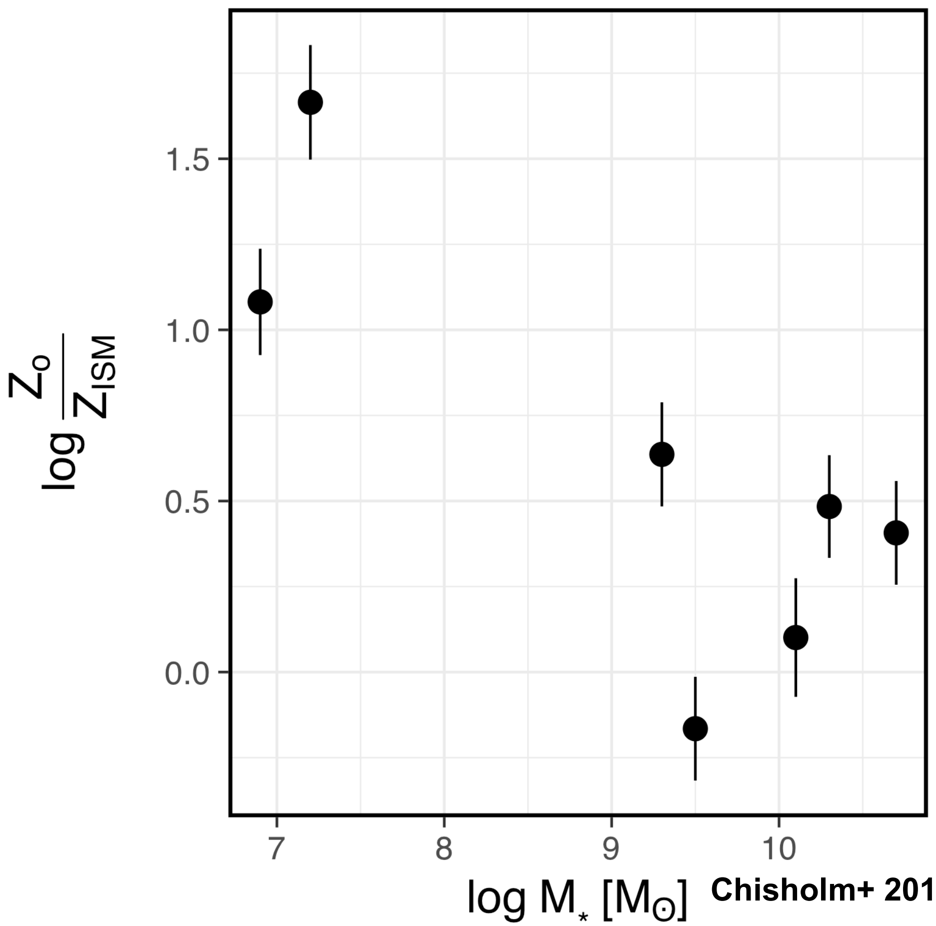
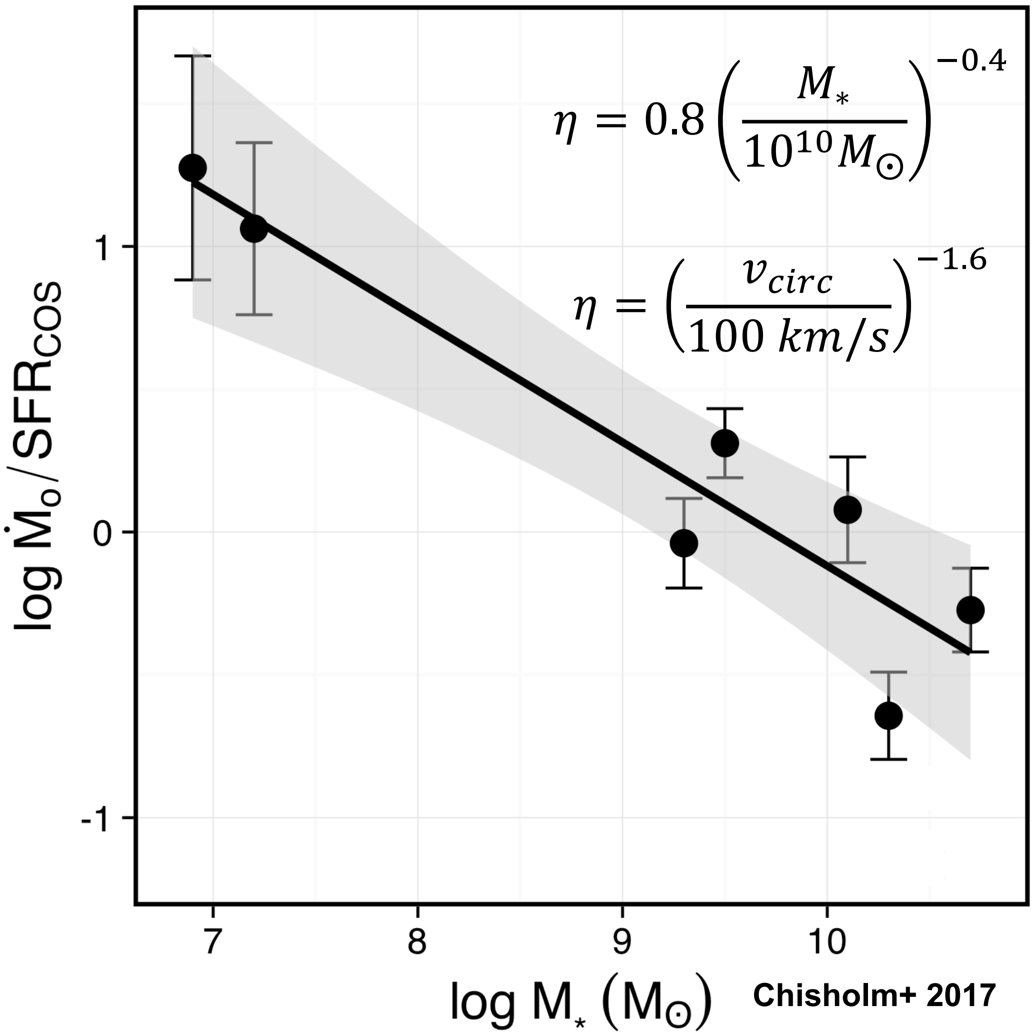


The inferred outflow metallicities are larger than the observed ISM metallicities: outflows are metal enriched



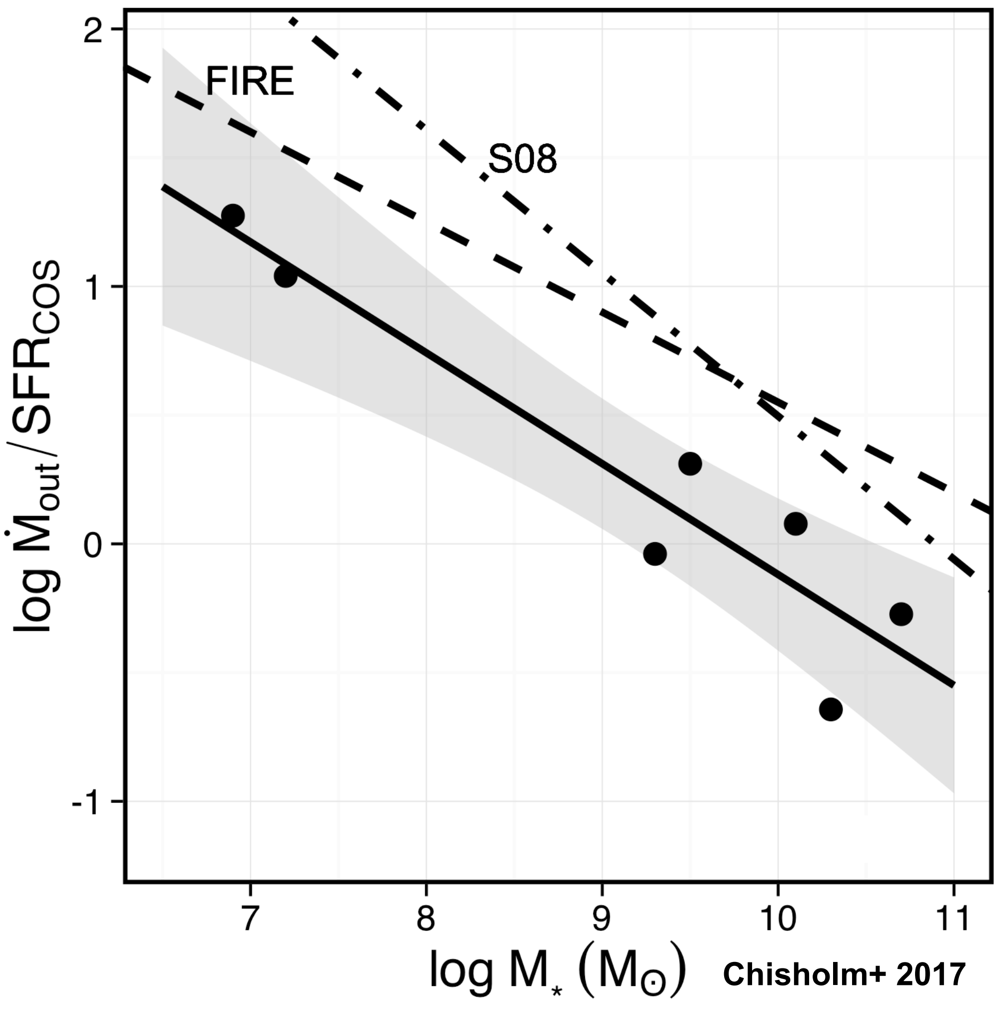
Chisholm+ 2018

Outflows from low-mass galaxies remove up to 10 times more mass than the galaxies convert into stars



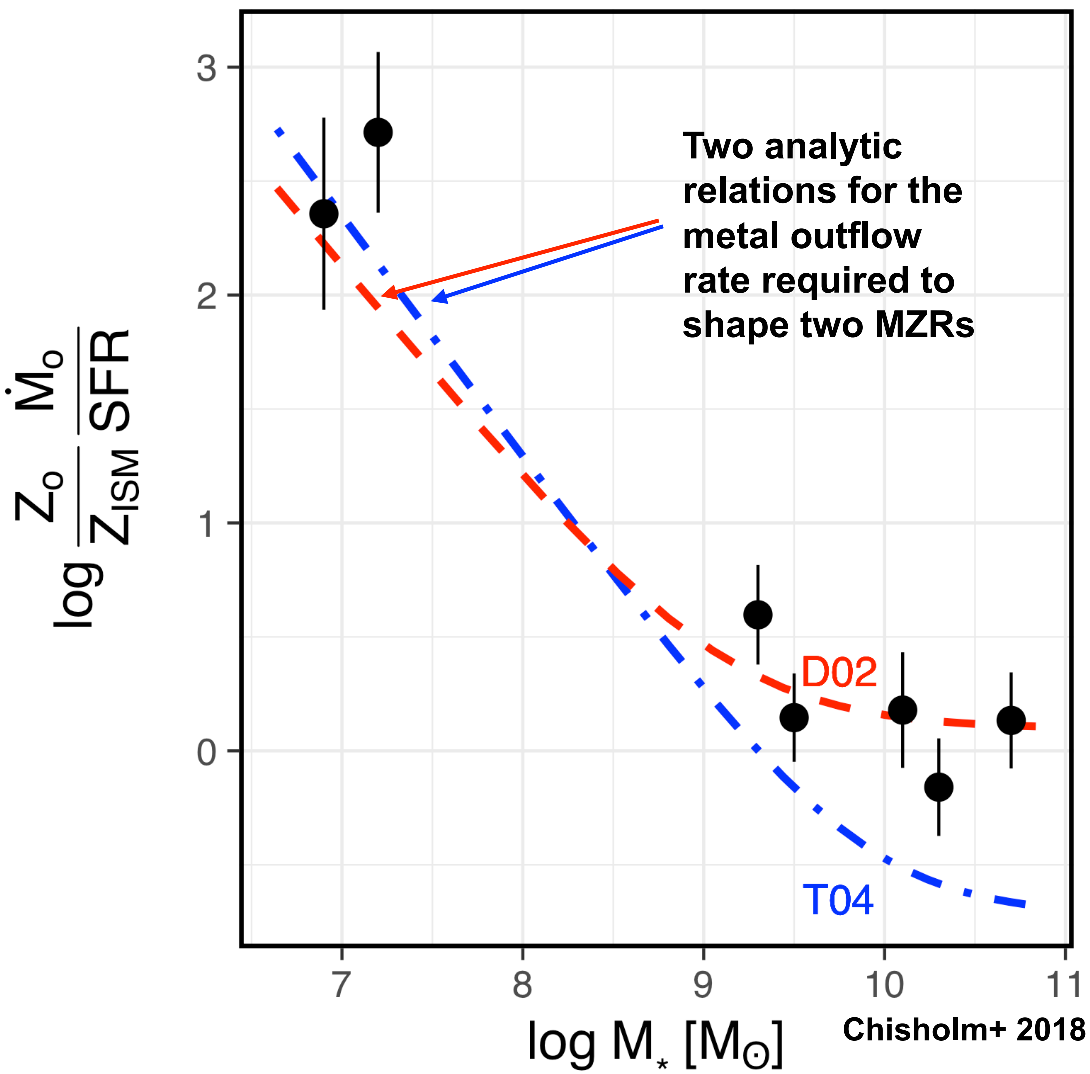
Chisholm+ 2017

These mass-loading factors have similar scalings as simulations, but generally lower values



Chisholm+ 2017

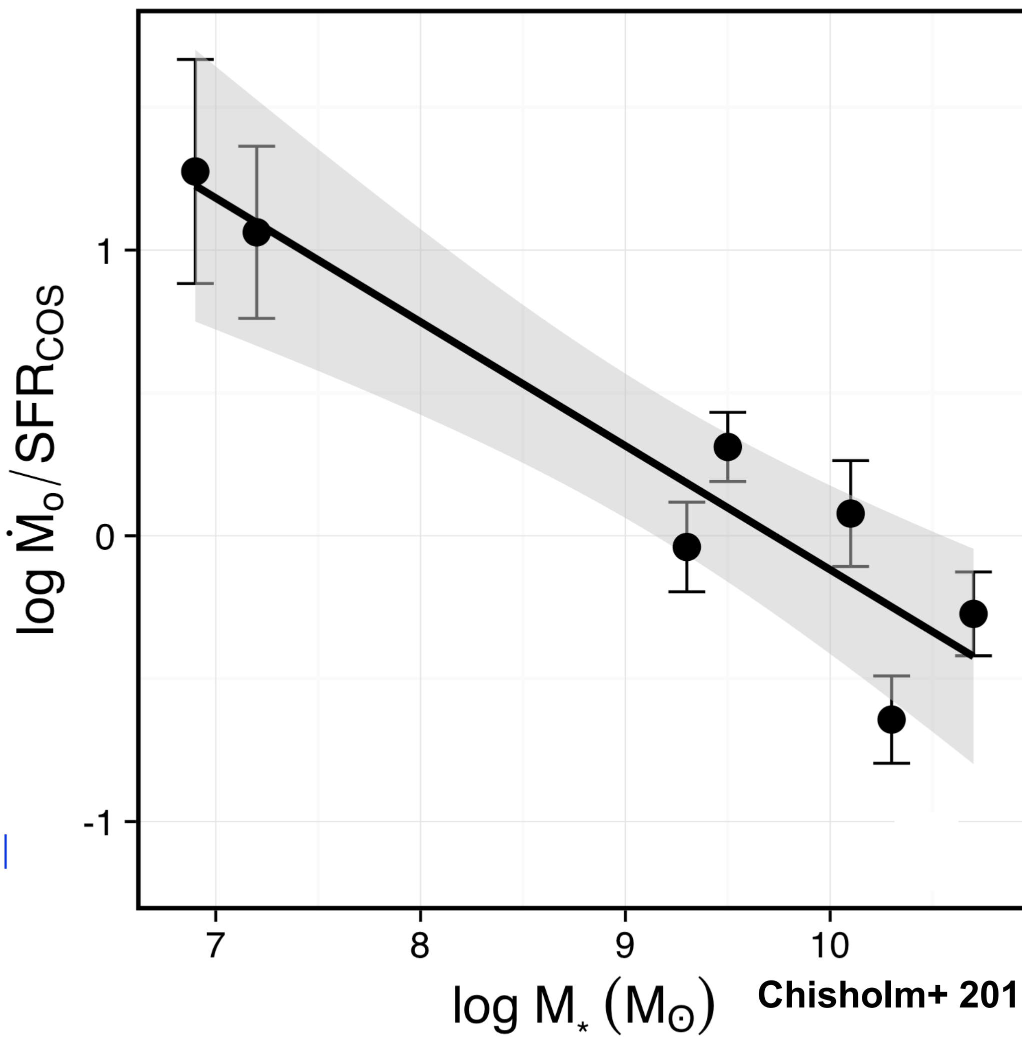
Metal-enriched outflows carry metals out of star-forming regions and into the CGM



Chisholm+ 2018

Can observed outflows explain the massive CGM?

$$\frac{\dot{M}_o}{SFR} = 0.8\left(\frac{M_*}{10^{10}M_\odot}\right)^{-0.4}$$



Chisholm+ 2017

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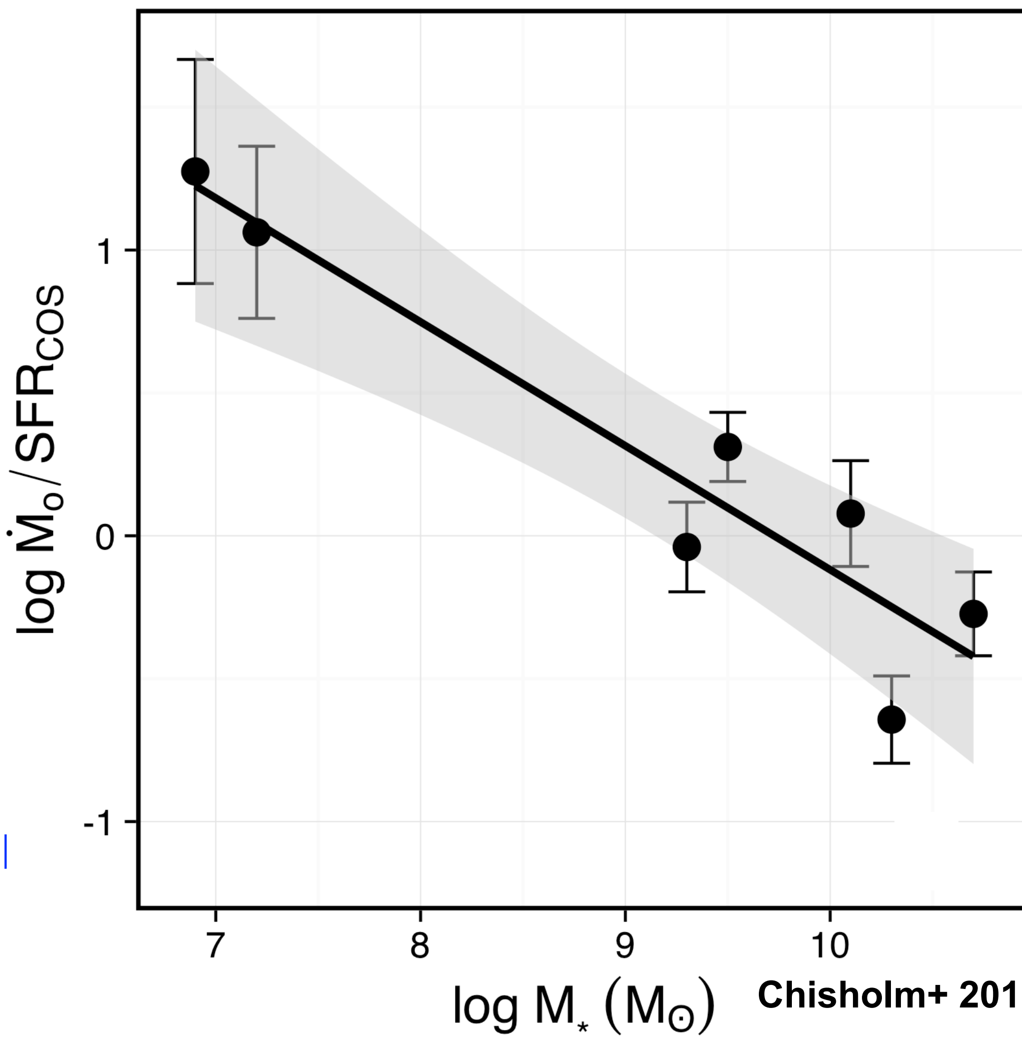
$$\dot{M}_o = \frac{dM_o}{dt};\, dt = \frac{dM_*}{SFR}$$



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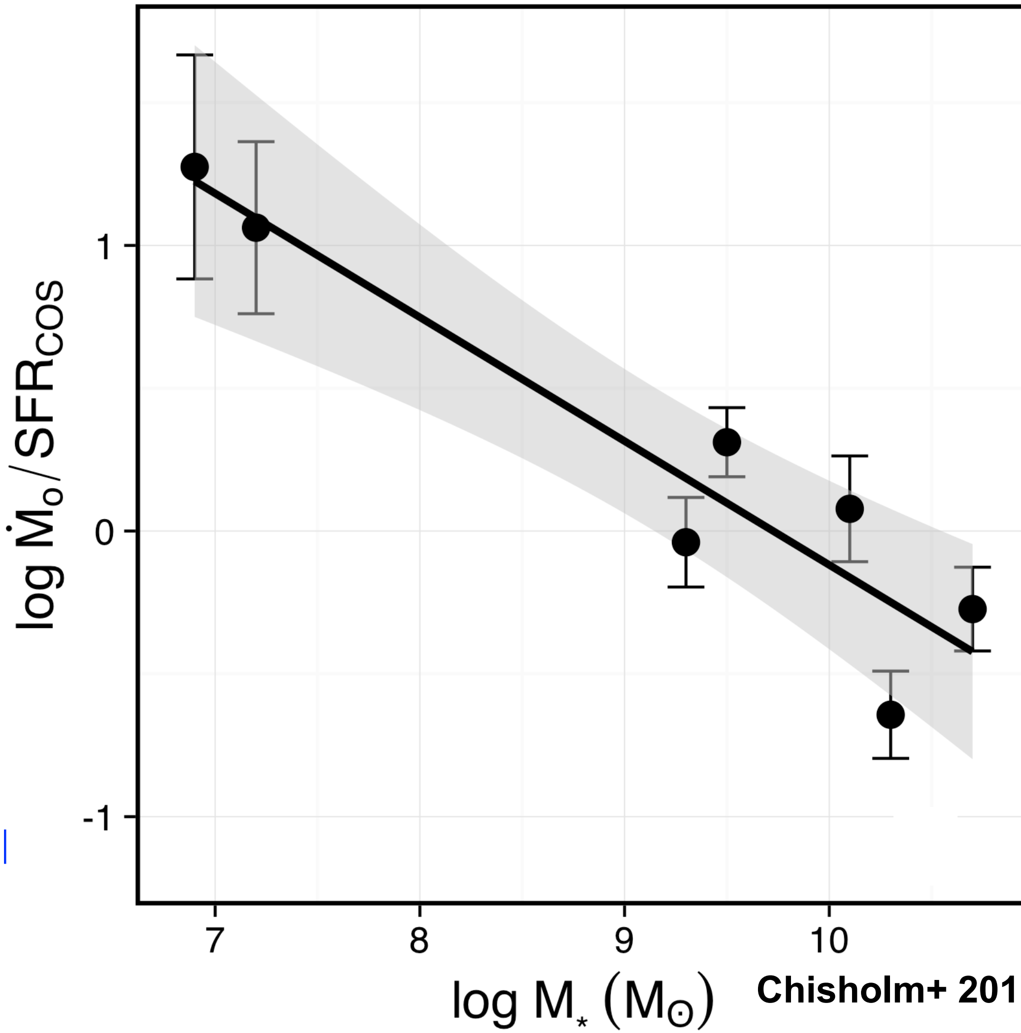

Chisholm+ 2017

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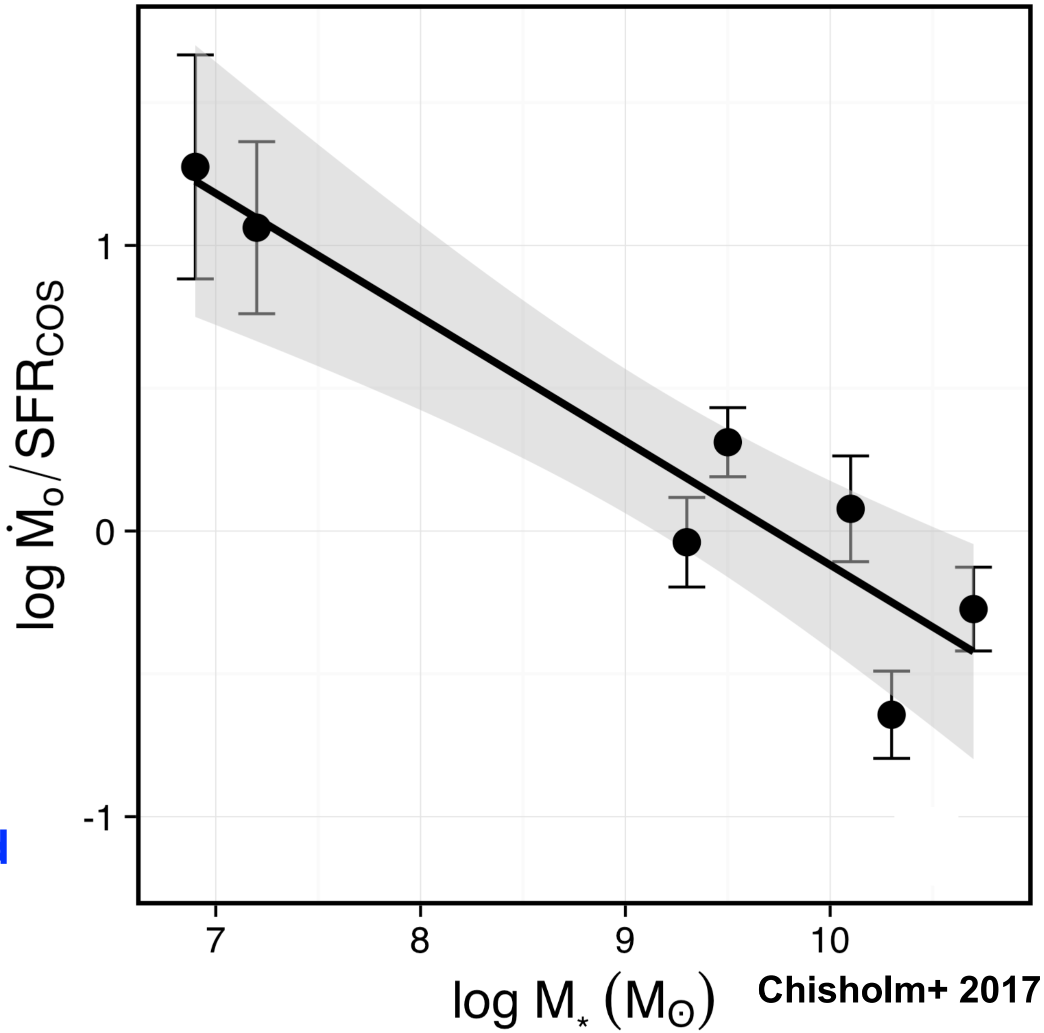
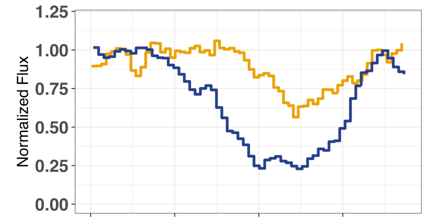
$$M_o = 1\times10^{10}M_\odot\left(\frac{M_*}{10^{10}M_\odot}\right)^{0.6}$$

Comparable to what is observed in the CGM, but doesn't include inflow, recycling, and other outflow components

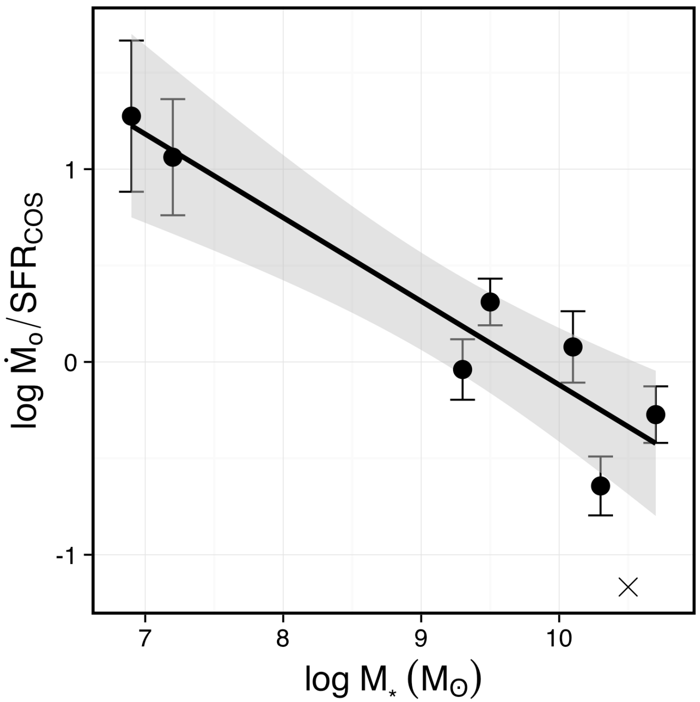


Chisholm+ 2017

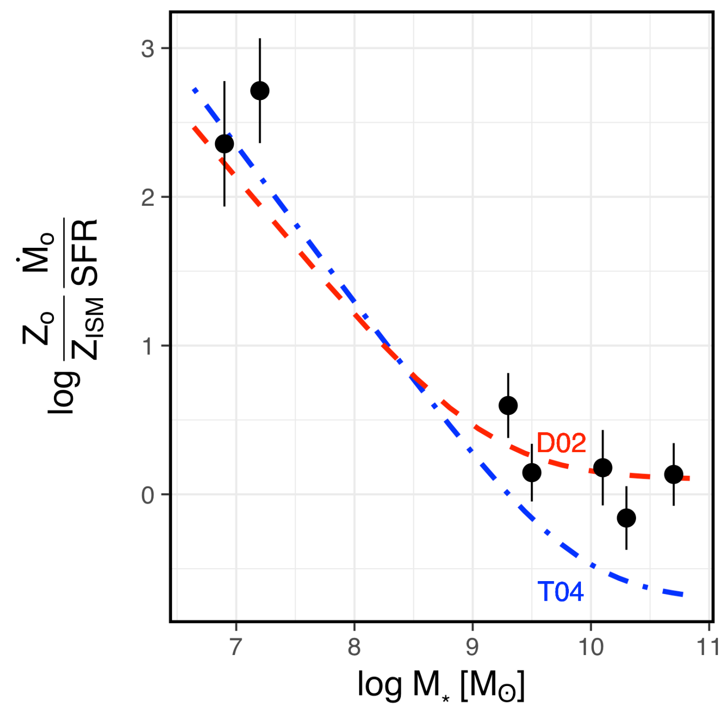
Conclusions



Outflow ionization varies from galaxy to galaxy

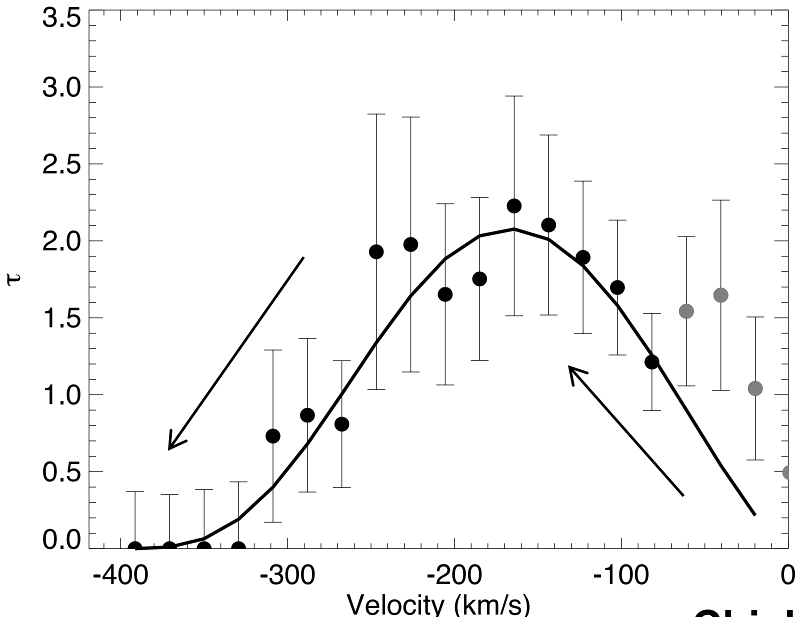


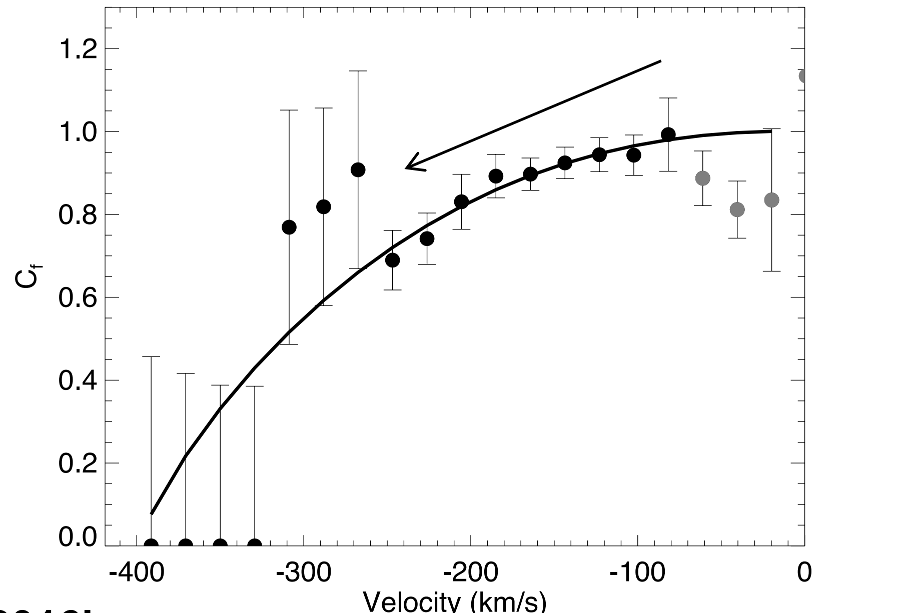
The mass-loading factor decreases with M_*. Outflows from low-mass galaxies remove 10 times more mass than SFR. The outflows remove a similar amount of gas as is observed in the CGM



Observed metal outflow rates are sufficient to establish the MZR

The Si IV optical depth and covering fractions change coherently with velocity





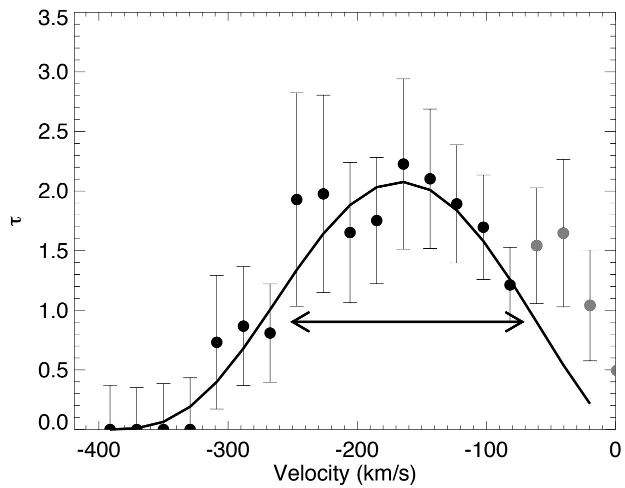
Chisholm+ 2016b

- **These distributions are from a single galaxy, NGC 6090**
- **Optical depth increases at low velocity, and decreases at high velocity**
- **Covering fraction steadily decreases from low velocities to 300 km/s**

The optical depth evolves because the density and velocity gradient change with velocity and radius

$$\tau(r) = \tau_0 n(r) \frac{dr}{dv}$$

$$\frac{n(r)}{n_i} = (r / R_i)^{\alpha}$$



$$\frac{v}{v_{\max}} = (1 - \frac{R_i}{r})^{\beta}$$

Broadening because gas at different radii are at different velocities