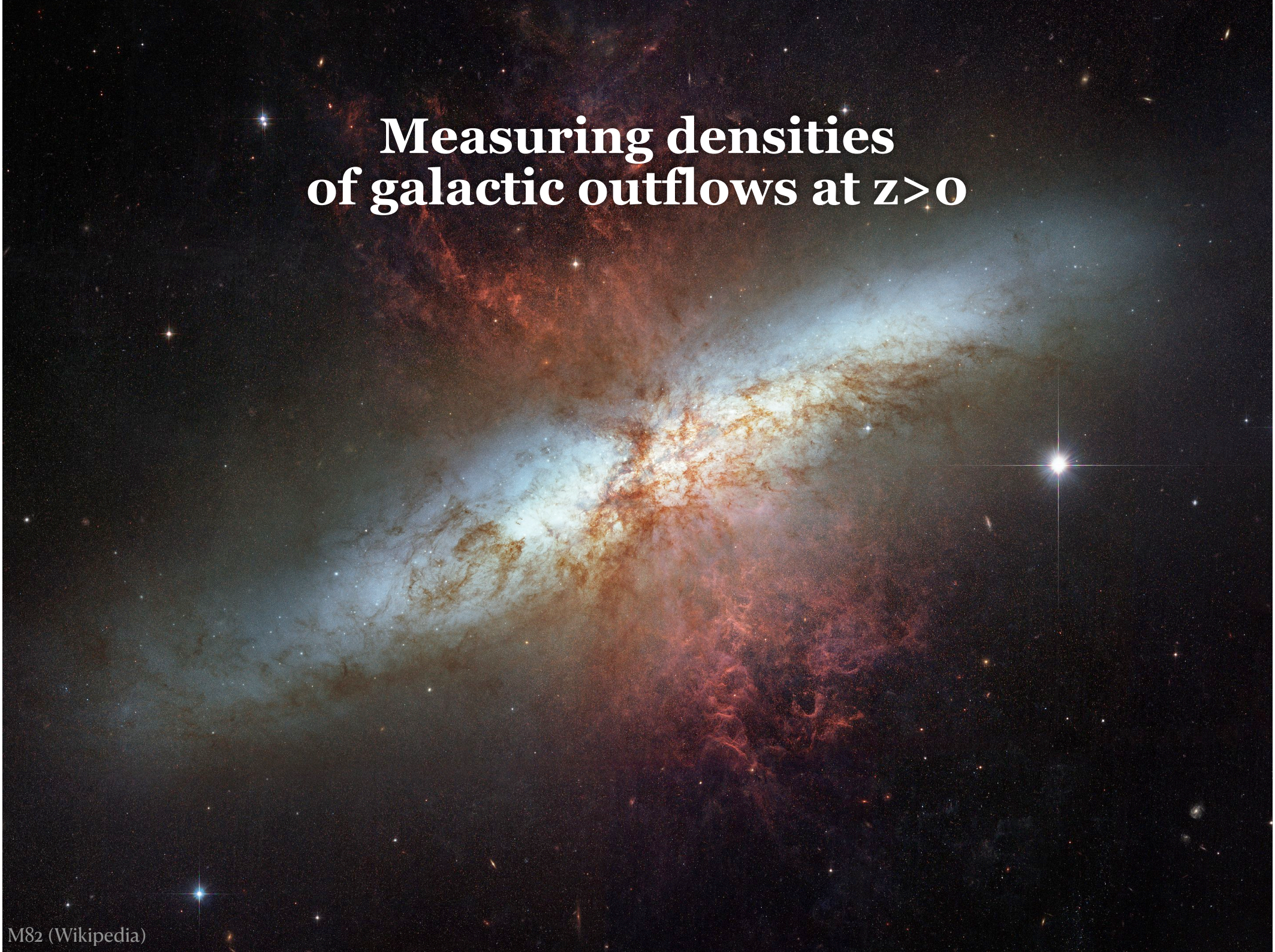
Measuring densities of galactic outflows at z>0



M82 (Wikipedia)

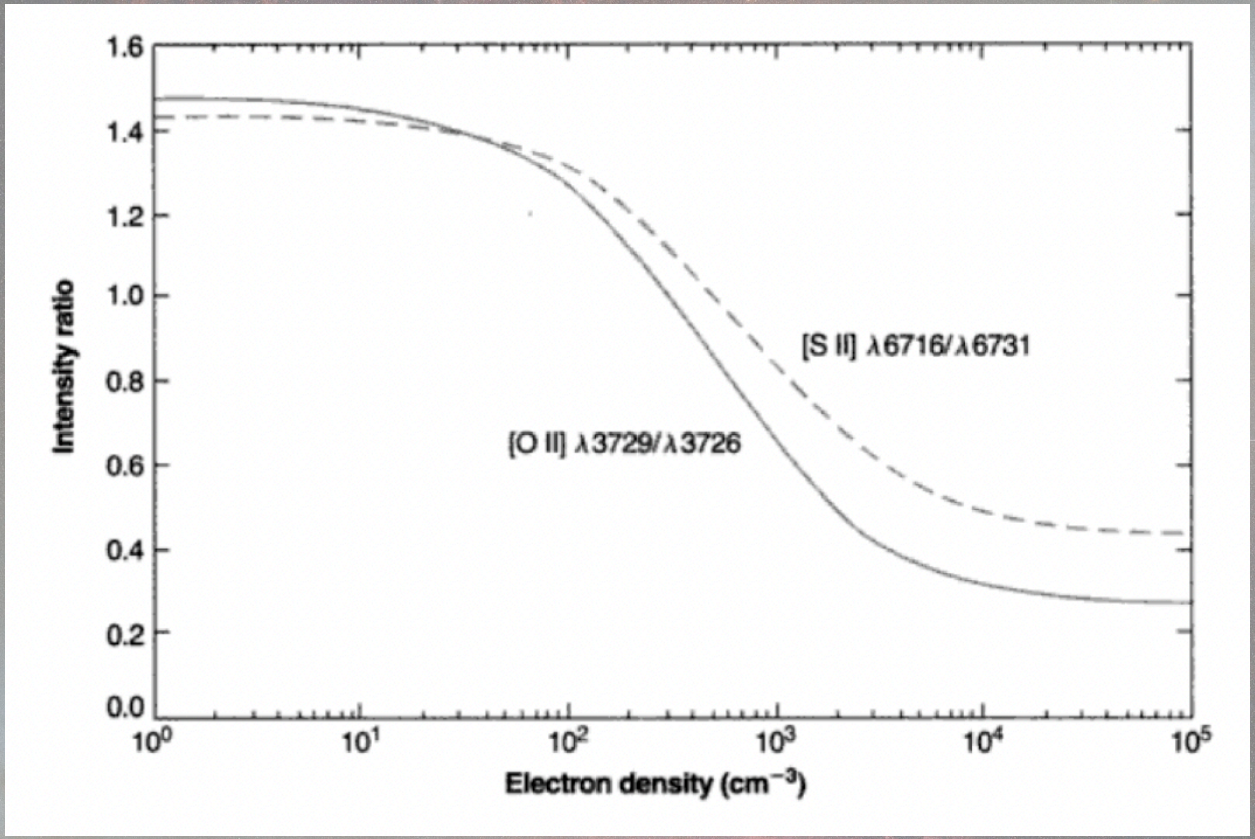
Measuring properties of galactic outflows helps us to understand and constrain feedback processes, galactic mass growth, metal enrichment, and much more.

The prime epoch to study galactic outflows and their impact on galaxy evolution is during cosmic noon, when baryonic processes likely dominated galactic evolution.

An important property in this context is a measurement of the density of outflowing material. A density measurement is necessary to calculate mass outflow rates and mass loading factors (typically used for the comparison to theoretical models), and at high redshift is currently one of the two main sources of uncertainty in calculations of outflow properties.

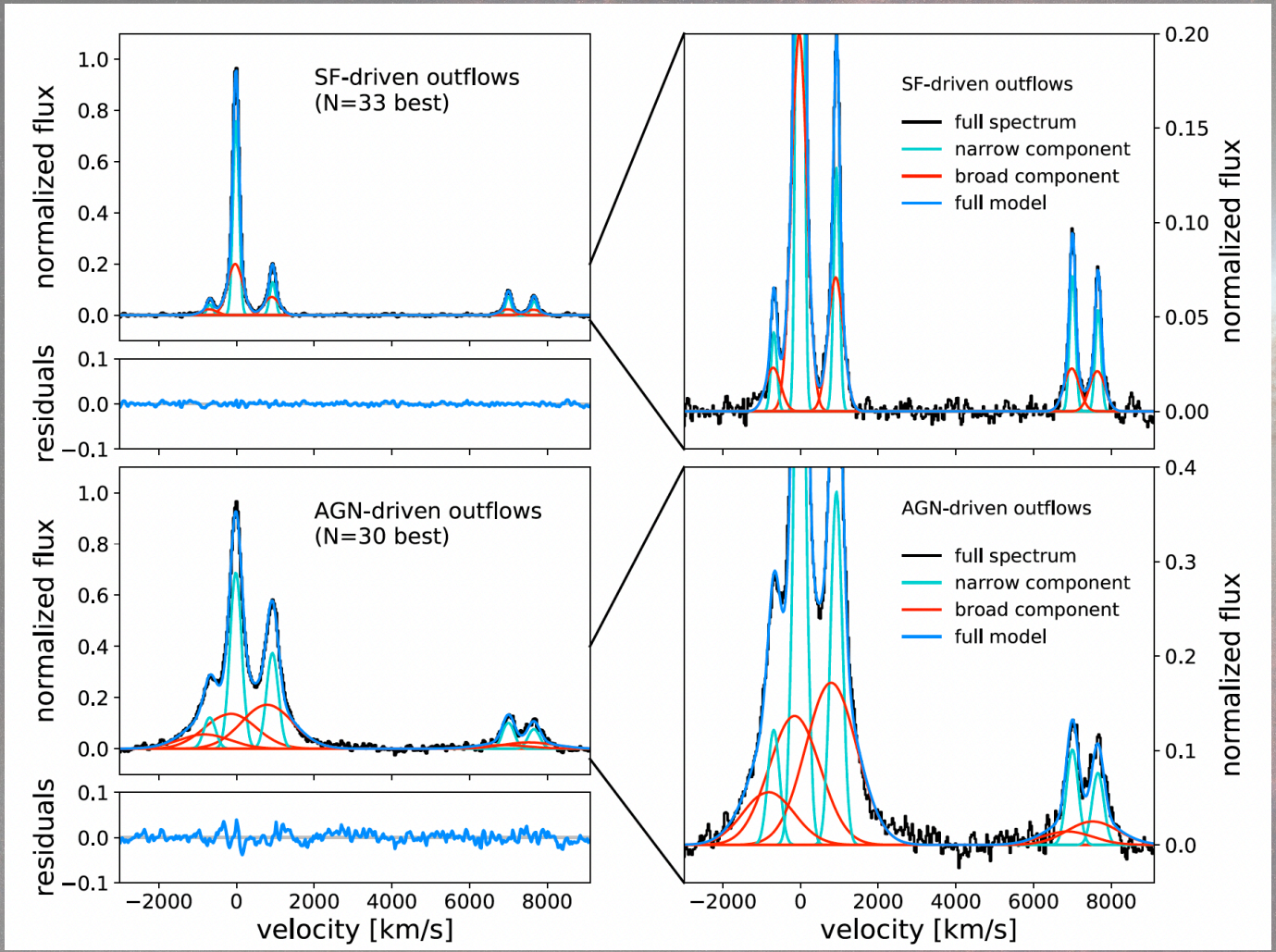
How densities are measured depends on the available indicators. For ionized gas, which is the dominant kinematic tracer of star-forming galaxies at $z\sim1-3$, density-sensitive rest-frame optical strong line doublets are typically used, such as [SII]6718/6733 or [OII]3727/3730.

Classical figure from Osterbrock 2005 showing the relationship between doublet line ratio and electron density.



A limitation of those tracers is the range in which they are sensitive - many high-z measurements are close to the low density limit.

Example of high-z data used to constrain outflow properties from Förster Schreiber+2019 (KMOS^3D data):



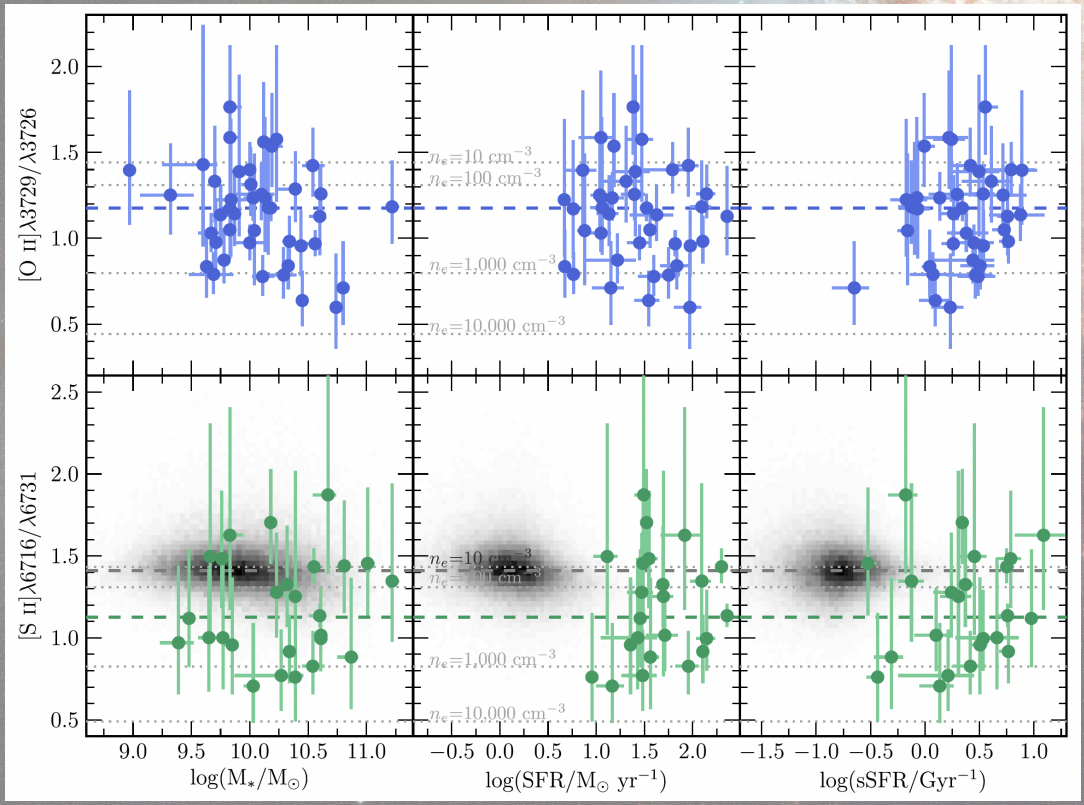
Here, the broad emission (orange) is associated with outflows. For strong outflows, the [SII] doublet starts to blend significantly and fitting multiple lines becomes necessary to constrain the ratio.

This work finds high densities in the outflows.

These are stacks of galaxies, as the [SII] doublet (to the right) is faint and tough to measure for individual objects.

There seems to be a picture emerging where high-z outflows show higher densities than their host galaxies (due to shocks?). What is currently missing is a systematic study of correlations of outflow densities with other galaxy properties - this requires high-quality data, stacking (i.e. a large enough data set), and line decomposition into host and outflow.

Ideally suited would be IFU data, f.i. from the large KMOS surveys (KMOS^3D, KLEVER, KROSS, ...).



There are some studies looking at correlations of densities and galaxy properties, but not distinguishing between host properties and outflows, e.g. Shimakawa+2015, Sanders+2016, or looking explicitely at galaxies without outflows, e.g. Davies+2021.

For individual objects at z>0 densities can rarely be measured robustly. Constraining and identifying correlations between outflow densities and global galaxy properties from stacks would therefore be extremely valuable for the community.

Literature to get started

outflows in the local Universe:

- classical reviews: Heckman 2002, Veilleux+2005, Heckman&Thompson 2017
- Arribas+2014
- Ho+2014
- Rupke+2017
- Fluetsch+2018 (comparison of multiple gas phases)

outflows at z~1—3:

- SFGs: Pettini+2000, Shapley+2003, Weiner+2009, Steidel+2010, Genzel+2011, Bouché+2012, Talia+2012,17, Förster Schreiber+2019, A.Concas+in prep., and so many more..
- AGN: Harrison+2012,16, Genzel+2014, Förster Schreiber+2014,19, Brusa+2015, Wylezalek&Zakamska 2016, A.Concas+in prep., and so many more..

lots of theoretical work as well

- e.g. Kauffmann+1993; Benson+2003; Murray+2005; Oppenheimer&Davé 2008; Dutton 2012; Muratov+2015; Bower+2017, Pillepich+2018, Nelson+2018, and so many more..