Studying Stellar Feedback with Galactic Outflow Scaling Relations

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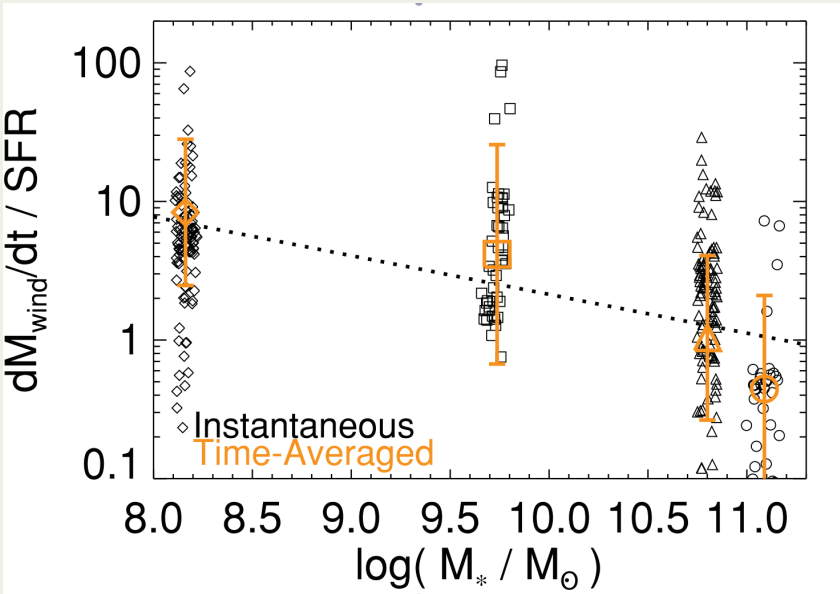
Wait, Star Formation is inefficient?

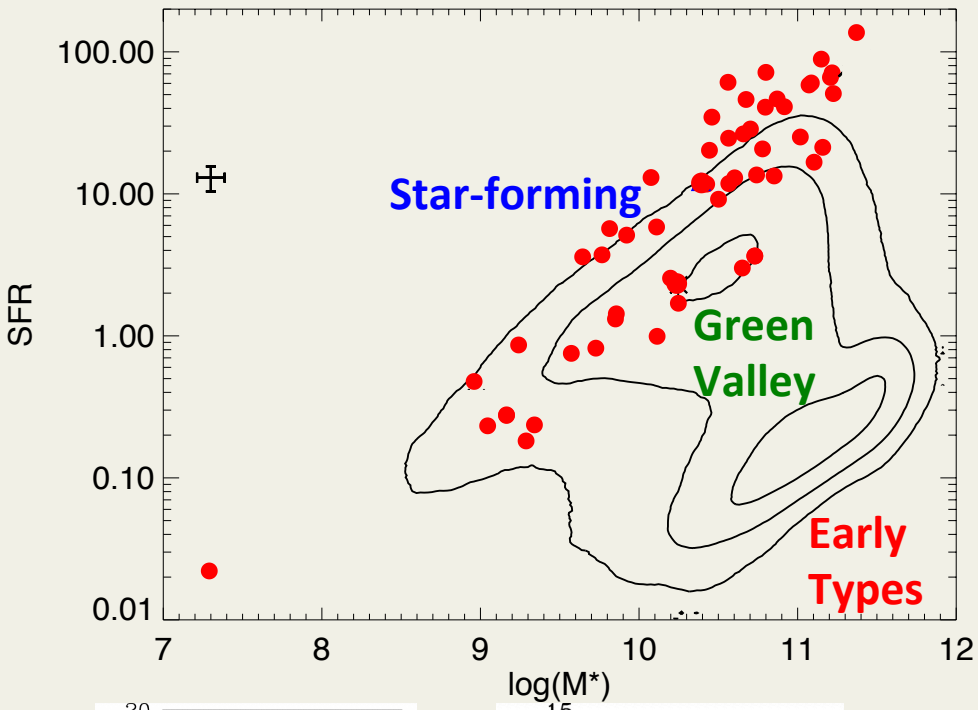


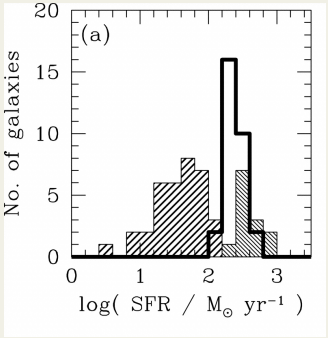
Hopkins et al. 2012

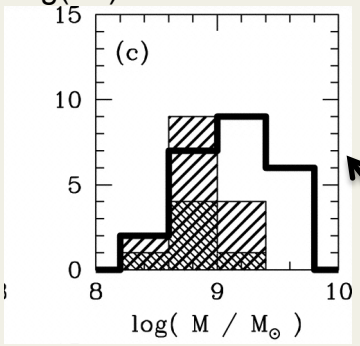
- Star formation is inefficient.
- Feedback from high mass stars impart energy and momentum into the ISM through supernovae, high energy photons, cosmic rays, and photo-electric heating. This energy and momentum launches gas into galactic outflows.
- Most simulations put feedback in by hand, or through scaling relations (used in Chris Hayward's simulations).
  - We are now entering the computational era where the vital physics can be incorporated into simulations on the scales that matter most
- **The goal here:** to reverse engineer the problem to develop an observationally based feedback prescription

A Local Star-Forming Sample

Contours are the total SDSS DR8 sample, including early type, and star-forming



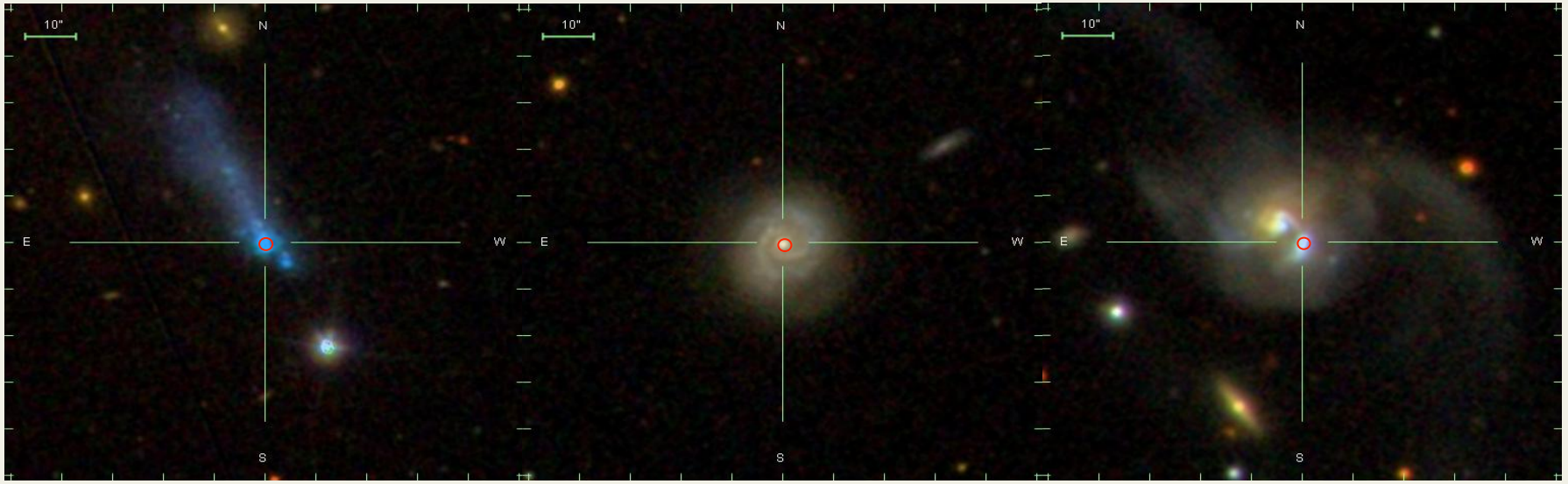




- We construct a sample of 51 local ($z < 0.26$) galaxies with UV spectra in the HST-COS archive.
- Stellar Masses and Star Formation Rates are calculated using a combination of WISE and GALEX fluxes.
- We roughly span the entire local star-forming sequence.

Host properties from Rupke et al. 2005 Na I study which mainly sampled high SFR galaxies

A Few Galaxies



SDSS gri images

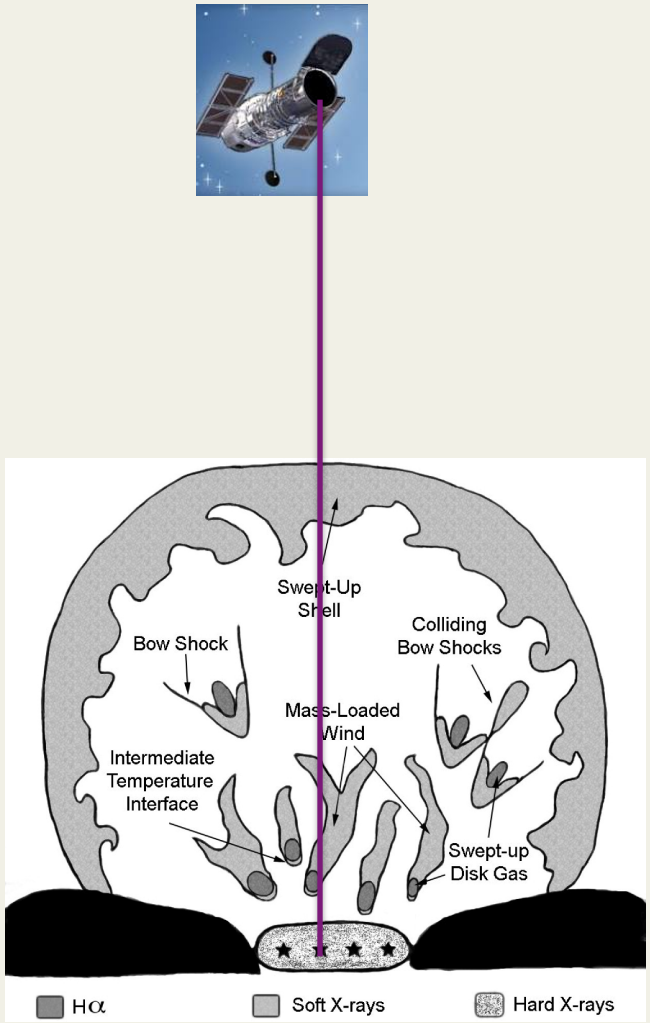
SBS 1415+437
- $\text{Log}(M^*/M_\odot) = 7.29$
- SFR = 0.02 $M_\odot$/yr

KISSR 1084
- $\text{Log}(M^*/M_\odot) = 10.65$
- SFR = 3 $M_\odot$/yr

NGC 6090
- $\text{Log}(M^*/M_\odot) = 11.02$
- SFR = 25 $M_\odot$/yr

- **Not pictured:** Very compact galaxies that are not resolved by the SDSS
  - Many of these compact galaxies are likely unresolved mergers (LBAs and Green Peas, see Overzier et al. 2011)
- We sample a wide variety of morphological types from normal galaxies, like irregulars and spirals, to mergers and interactions

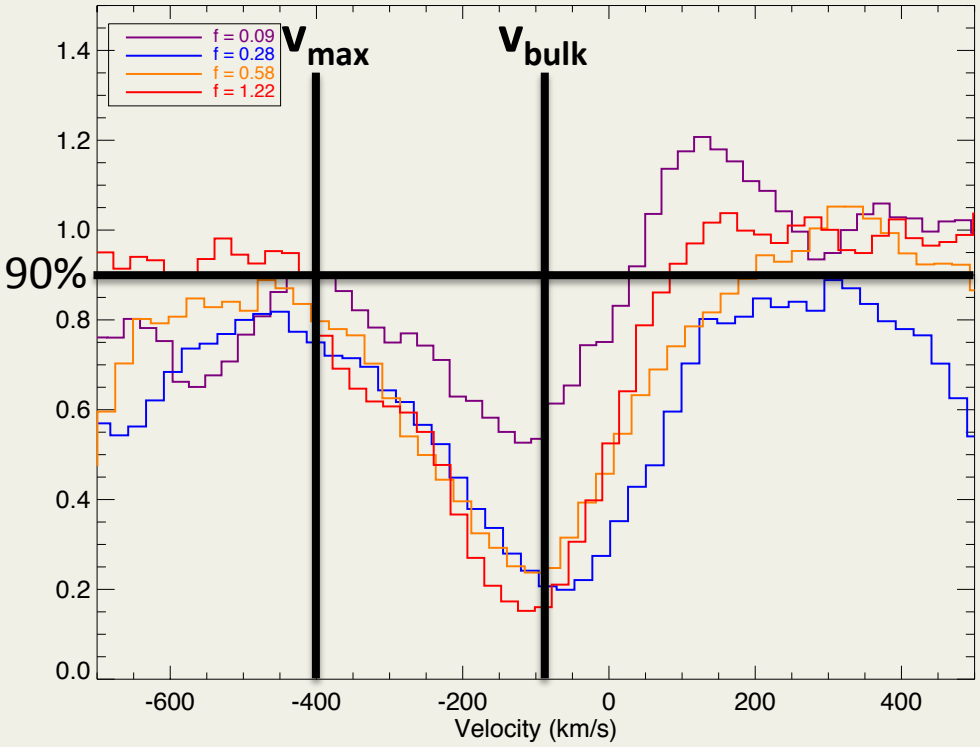
Absorption Probing Outflows



Cooper et al. 2008

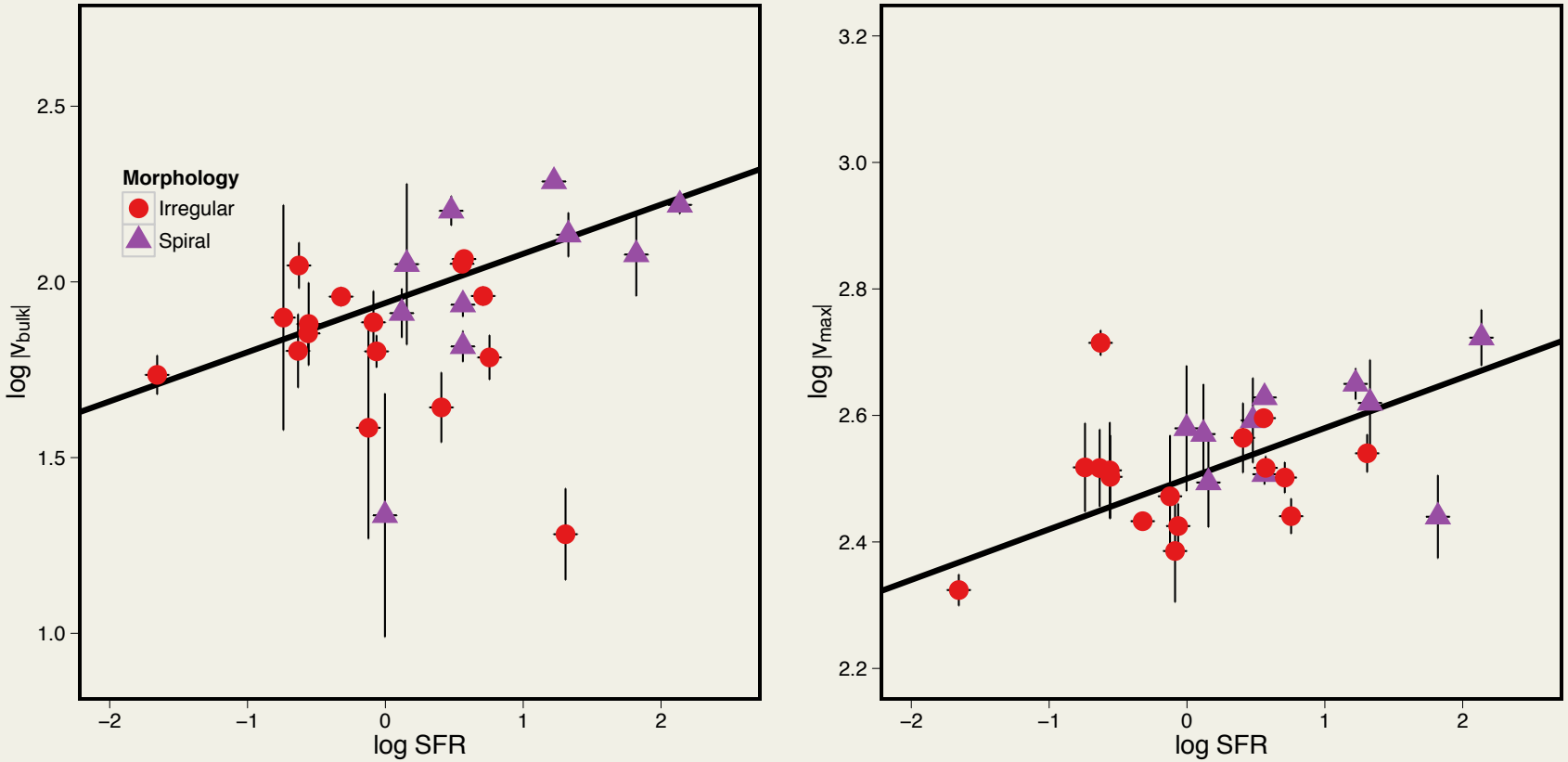
- We use the UV spectra from COS to observe gas absorbing background stellar continuum
- Absorption probes the gas along the line of sight between the observer and the continuum source.
- We use Si II to probe the 10^4 K gas entrained in the outflow

Kinematics from Si II Lines



- Kinematics are measured in 2 ways:
  - The centroid velocity (v_{bulk})
  - The velocity at 90% of the continuum (v_{max})
- We measure column densities from the Si II
- Mass outflow rates are calculated by converting Si II to H and assuming an outflow geometry

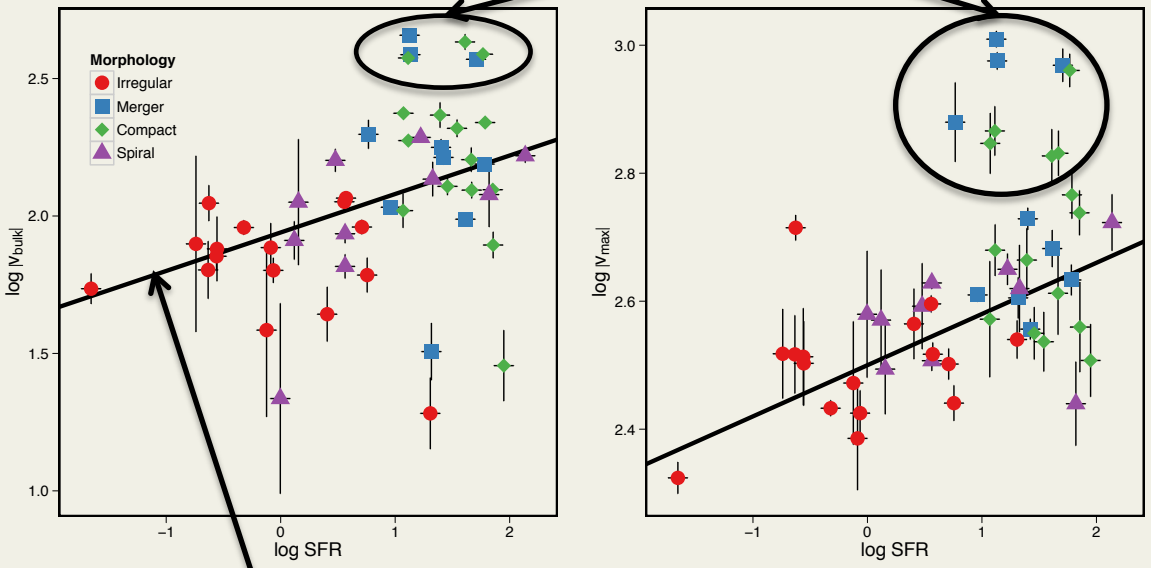
Examining “Normal” Galaxies



The normal galaxies follow a modestly tight, yet shallow, trend between SFR and outflow velocity. The trend-line here is the trimmed fit for the entire sample.

Supernovae Driven Outflows

Mergers above the trend



$$v_{out} \propto SFR^{0.14\pm0.03}$$

Mckee & Ostriker 1977

$$v_{out} \propto E^{0.15}$$

$$E = E_{SFR} \varepsilon t_{in} SFR$$

$$\therefore v_{out} \propto SFR^{0.15}$$

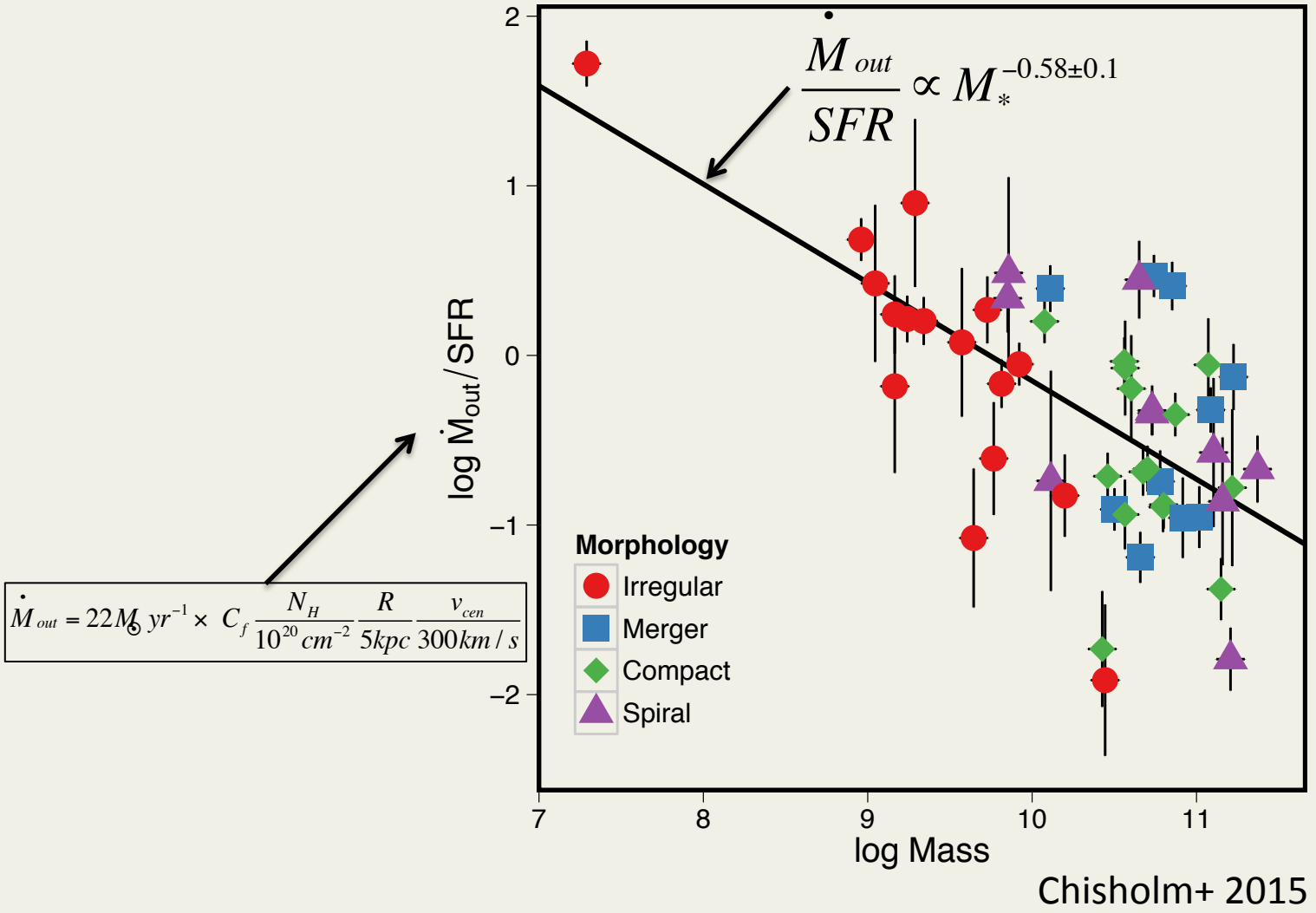
Expected Velocity for blastwave

Supernova energy per solar mass formed

Expected scaling of velocity

Compared to expected radiation pressure scaling of $v_{out} \sim SFR^{0.25}$

The Mass-Loading Efficiency

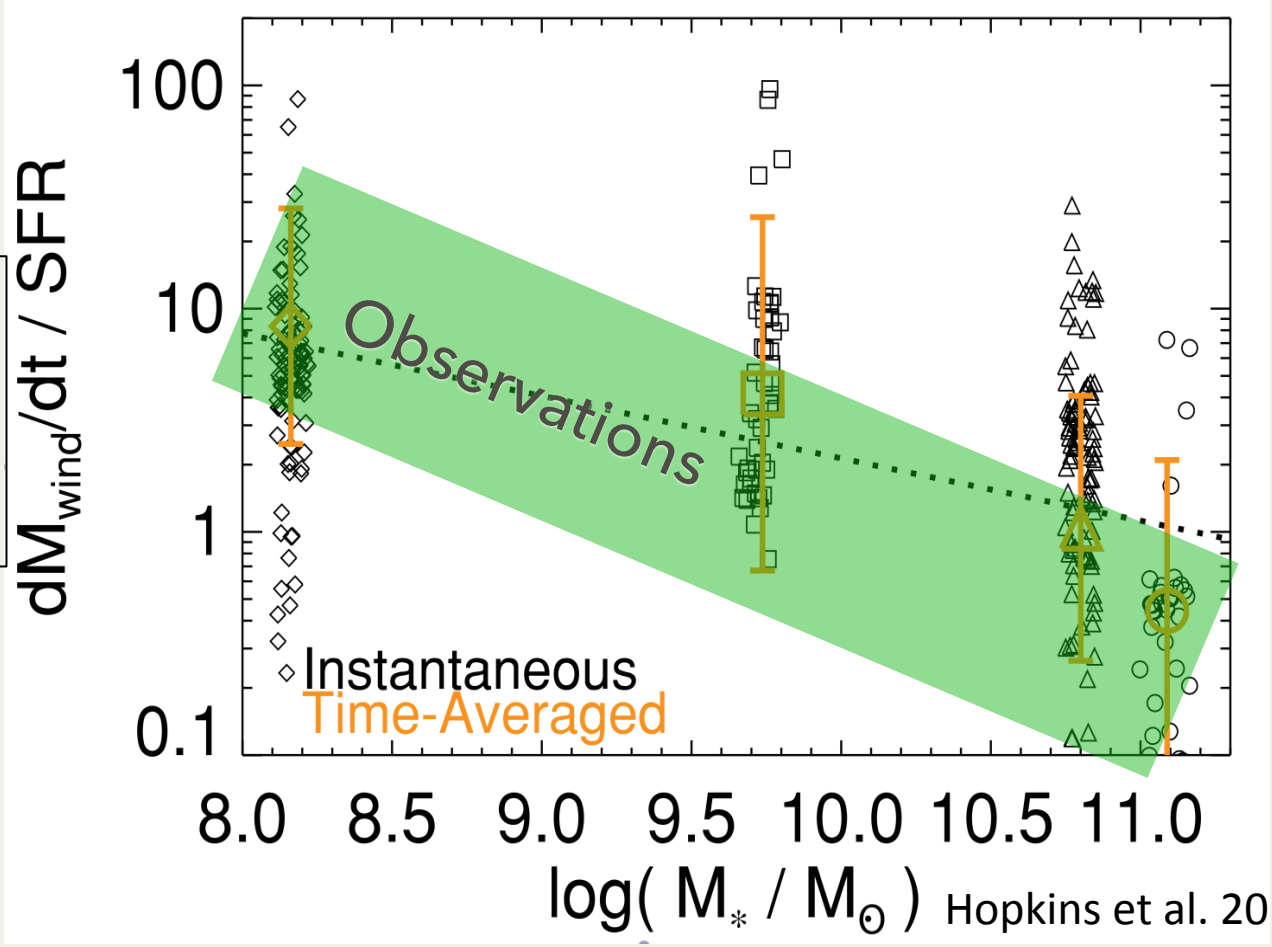


The Mass-Loading efficiency scales strongly with the stellar mass. The scaling also indicates supernovae driven outflows.

Chisholm+ 2015

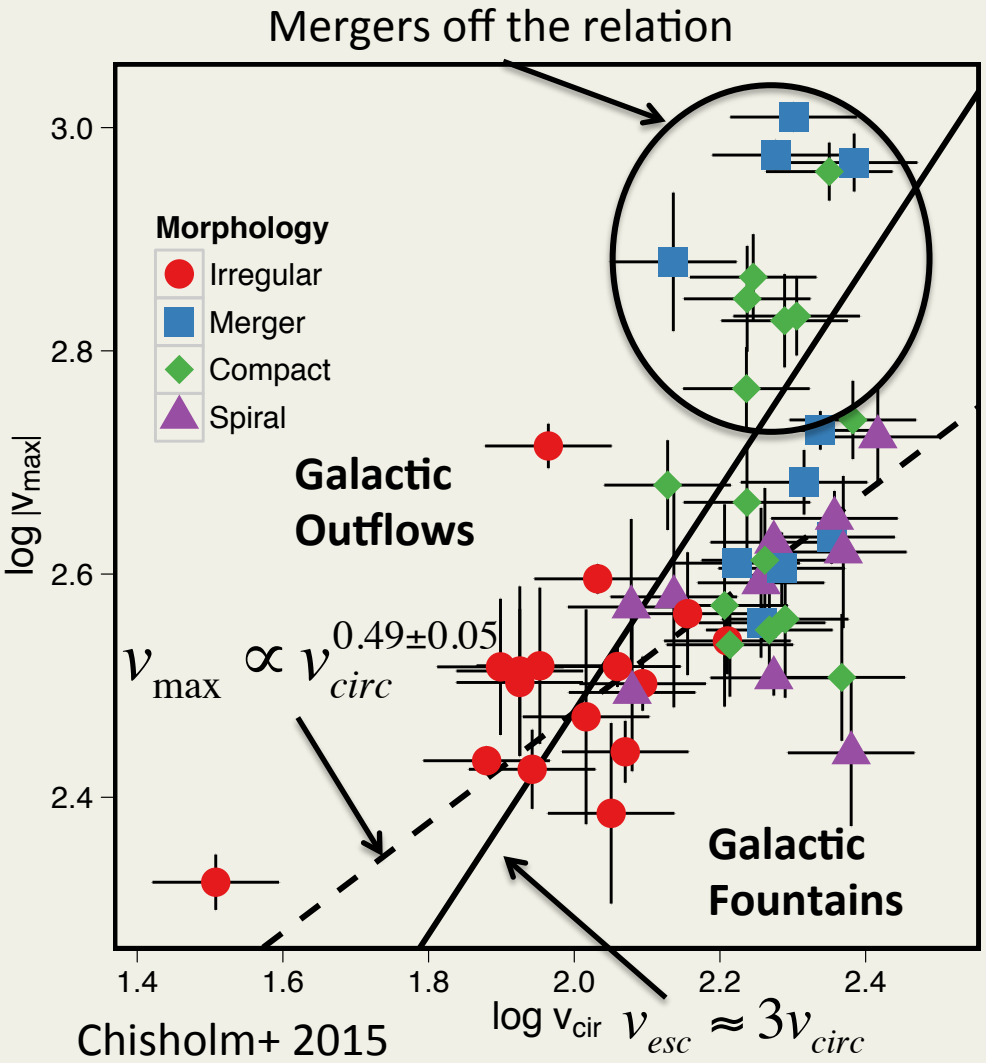
How Do Simulations Compare?

Simulations are marginally consistent with observed mass-loadings



Hopkins et al. 2012

A Threshold to Lose Gas



- There is a log critical Mass of 9.5 ± 0.2$M_{\odot}$, or 100 km/s.
- Normal galaxies above this mass retain all the gas
- All galaxies below this mass lose ***some*** gas
- Compare to $v_{out} \sim v_{circ}$ for radiation pressure (Murray+ 05)

Summary

- We present a sample of 51 nearby star-forming galaxies, observed in the UV. The kinematics and mass outflow rates are measured with Si II absorption lines.
- We study trends in the outflow velocity with SFR, and find that supernovae likely power the outflows.
- Simulations roughly match the observed mass outflow relation.
- There is a critical log stellar mass of $9.5 \pm 0.2\ M_{\odot}$ (v_{circ}=100km/s).
  - Below the critical mass ***some*** of the outflow escapes the gravitational potential of the galaxy, while galaxies above this threshold do not lose any gas through outflows
- Some mergers and interactions have a temporarily increased outflow velocity.