Cool Gas Flows Around Star-Forming Galaxies at $z \sim 0.5$

~ or ~

All Aboard the BC Express:
Starting and Ending an Incredible Journey

Kate Rubin
MPIA

J. X. Prochaska, David Koo, Drew Phillips (UCSC)
Crystal Martin (UCSB)
How did this happen?

Catching the Start of the Journey: Outflow

Starburst galaxy

Credit: M. Westmoquette (UCL), NASA/ESA

Keck

Saturday, June 16, 2012
Our Sample: Run-of-the-mill Star-Formers

Spectroscopy:
- Keck/LRIS survey to B(AB) < 23 (3 hours/object)
- 180 - 300 km/s FWHM resolution
- ~ 105 galaxy spectra at 0.3 < z < 1.4, median z ~ 0.5, median S/N ~ 9 pix⁻¹
- coverage of MgII 2796, 2803 and FeII 2586, 2600

AEGIS: Barro et al. 2011

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HST/ACS Imaging (GOODS and EGS)
Ground-Based Optical / Near-IR Imaging (GALEX - 24\(\mu\)m):
- FIREWORKS (GOODS-S): Wuyts et al. 2008
- RAINBOW (EGS): Barro et al. 2011
- MOIRCS Deep Survey (GOODS-N): Kajisawa et al. 2010

AEGIS: Barro et al. 2011
What does “outflow” mean?

I(\lambda) = F(\lambda, \lambda_0, C_f, b_D, N)

A Velocity “Component”:
- central wavelength (\lambda_0)
- Doppler parameter (b_D)
- column density (N)
- covering fraction (C_f)

We use 2 “components”:
- ISM: \lambda_0 = systemic wavelength
- ISM: C_f = 1
- FLOW: 4 free parameters
  6 free parameters!

We sample parameter likelihood space using “MCMC” to calculate robust parameter errors (e.g., Sato et al. 2009)
What does “outflow” mean?

Fell 2586, 2600

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Relevant Measurements: \( EW_{flow}, N_{flow}, \max v = v_0 - b_D/\sqrt{2} \)
My first pie chart: cool gas kinematics at $z \sim 0.5$

What determines these percentages? Well...
It’s all about...

see also Kornei+2012

Rubin+2012, in prep
...which suggests that nearly all star-forming galaxies at \( z \approx 0.5 \) are driving winds (with opening angle \( \sim 70^\circ \)).

Rubin+2012, in prep

see also Kornei+2012
So, how fast are these winds?

Weiner+09, z~1.4: yes
Kornei+12, z~1: weak
Chen+10, z<0.2: no
Rupke+05, LIRGs: no
Martin+05, dSB+ULIRGs: yes

(assume $M_h = 10M_\odot$)

$V_{esc}$ (km s$^{-1}$)

500 1000 1500
And how much material do they carry?

Higher SFRs → higher $N_{\text{flow}}, C_f, \text{flow}, \text{or both}$

- Weiner+09, $z \sim 1.4$: yes
- Chen+10, $z < 0.2$: yes
- Rupke+05, dSBs+LIRGs: yes
- Saturday, June 16, 2012
And how much material do they carry?

- Assume solar metallicity, no ionization correction, no dust depletion.
- $N_H > 10^{19.5} \text{ cm}^{-2}$

- Assume $R = 4 \text{ kpc}$, $v = 400 \text{ km/s}$
- $dM/dt > 1.2 M_\odot/\text{yr}$

COS-Halos measure $M_{CGM} \sim 10^{10-11} M_\odot$
Catching the End of the Journey: **Inflows**

Rubin, Prochaska, Koo & Phillips 2012
Again, it's all about inclination.

outflows, systemic absorption

inflows
Inflows: they’ve been there all along...

40% of sample has comparably strong red EWs
Conclusions

We detect winds in 66% of normal, star-forming galaxies at $z \sim 0.5$

The strong dependence of detection rate on inclination suggests winds are in fact ubiquitous

Winds do not escape from host halo, but push on $> 1.2 \, M_\odot/yr$

Wind $C_f$ and/or $N_{\text{flow}}$ increase with SFR

Inflows are detected primarily in edge-on galaxies, but are also only detectable in the absence of a wind