### EVOLVING PHYSICAL PROPERTIES OF STAR-FORMING GALAXIES AT 0<Z<4

Fergus Cullen IfA, University of Edinburgh

M. CIRASUOLO, R.J. MCLURE, J.S. DUNLOP, L.J. KEWLEY, R.A.A. BOWLER



"The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312725''

### MOTIVATION: O3N2 BPT DIAGRAM



High redshift galaxies offset from local star-forming sequence in the [OIII]/H $\beta$  vs [NII]/H $\alpha$  BPT diagram

Erb+2006, Shapley+2005, Brinchmann+2008, Kewley+2013, Steidel+2014, Shapley+2015

### MOTIVATION: METALLICITY DISCREPANCIES

Steidel+ 2014 8.8  $<z>=2.30\pm0.15$ 8.6 12+log(0/H) [03N2] Pettini+Pagel 2004 8.4 calibration 8.2 8 [03N2]=0.87\*[N2]+0.94 8.8 8.4 8.2 8.6 8  $12 + \log(O/H)$  [N2]

Zahid+ 2014, Sanders+ 2015

## MOTIVATION: BPT DIAGRAM



Position on the star-forming sequence determined by: metallicity, ionization parameter, electron density, shape of EUV spectrum

## MOTIVATION: BPT DIAGRAM



Can theoretically predict evolution of the abundance sequence

# MOTIVATION: N/OVARIATIONS



At low metallicity nitrogen produced by regular helium burning in massive stars At high metallicities excess nitrogen can be produced via the CNO cycle

# [OIII]/HB VS. REDSHIFT

 Model the evolution of the [OIII]/Hb ratio as a function of redshift and compare to observations.

۲

No dependence on N/O ratio variations

Allows us to extend samples out to  $z \sim 4$ 



### **Local Reference Sample:**

~50,000 SDSS spectra from the DR7 MPA catalogue at 0.02 < z < 0.12

**3D-HST:** 

Cullen+ 2014



Using an independent reduction of the 3D-HST grism data have a sample of  $\sim$  200 galaxies at 1.3 < z < 2.3

### [OIII]/HB VS. REDSHIFT WITH 3D-HST

### 3D-HST: 1.3 < z < 2.3



#### HOLDEN+2014: 3.2 < z < 3.7



• Additional sample of 48 galaxies at 3 < z < 4 from Troncoso+2014 and Holden+2014



# THEORETICAL MODELS



Cullen+ submitted

The metallicity vs. redshift relation taken from Dave+2011a,b. This theoretical relation is in agreement with current data out to z ~ 2 using the Kobulnicky+Kewley 2004 metallicity calibration

### **IMPORTANT POINT:**

 Since we separately constrain the ISM pressure (electron density), the increasing ionization parameter models represent an increase in the number of hydrogen ionizing photons incident on a unit area of the ISM.

 $\mathcal{U} \propto Q_0^{1/3} n_e^{1/3} \epsilon^{2/3}$ 

Sanders+2014

two ways to achieve this:



### wavelength

 $F_{\lambda}$ 

wavelength

# THEORETICAL MODELS

Test four scenarios:

- I. Ionization parameter and ISM pressure remain constant with redshift
- 2. ISM pressure only increases with redshift
- 3. Ionization parameter only increases with redshift
- 4. Both ionization parameter and ISM pressure increase with redshift



# LINE LUMINOSITY SELECTION EFFECTS



Increasing line luminosity thresholds in SDSS galaxies mimics line ratio evolution observed at high redshift

# CORRECTING FOR LUMINOSITY BIAS

Cullen+ submitted



As found by Juneau+2014, [OIII]/Hb correlates with [OIII] luminosity Run set of simulation on the 3D-HST data to determine luminosity limits

# CORRECTING FOR LUMINOSITY BIAS



We find this simple and clean method does not produce bias the stellar mass or star formation rates high redshift sample



# [OIII]/HB VS. REDSHIFT

The line ratio evolution not consistent with the pure metallicity evolution models

Data imply that the ionization parameter rises with redshift

Cannot definitively say whether this also coincides with a rise in the ISM pressure

## IMPROVING RESLUTS





density!

Models more clearly separated at lower luminosity limits

### MEASURING METALLICITIES



Ionization parameter must be accounted for when measuring metallicities from nebular lines

### CONCLUSIONS

- Redshift evolution of the [OIII]/Hb ratio cannot be explained by metallicity evolution alone.
- Instead the ionization parameter must increase with redshift (also maybe the ISM pressure?), meaning more Hydrogen ionizing photons incident on a unit area of the ISM (denser star forming clusters?)
- Metallicity diagnostics calibrated with local Universe galaxies are not valid at high redshift.
- Metallicity diagnostics have to account for variations in ionization parameter and ISM pressure.